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AN INVESTIGATION INTO SHOE LAST DESIGN IN RELATION TO FOOT MEASUREMENT AND SHOE FITTING FOR ORTHOPAEDIC FOOTWEAR

by

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ABSTRACT

The purpose of this research is to investigate the relationship between shoe last and foot shapes using fit assessment and foot measurement techniques developed from volume and orthopaedic footwear.

A shoe last is a 3-D form usually made in wood, plastic or aluminium. It is this shape which forms the basis of the fit, size and style of the shoe in relation to the foot.

This thesis begins with an introduction and overview intended to raise awareness of existing problems. The literature relating to the research is then reviewed, together with background information. There follows the research, consisting of four experiments; made to measure lasts, shell shoe fitting, limits of last allowance and toe room allowance.

As part of a larger international research project at the ME&P Department into an integrated measurement and design system for orthopaedic footwear, this particular research concentrates on the specification of shell shoe fitting and shoe/last design for individuals. The weight-bearing and toe extensions are measured from the inside shoe to improve toe room requirement in last design. A scientific approach to last design has been achieved specifically by studying the cross-sectional relationship between the foot and last.

Clarks Shoes Ltd. provided volunteer subjects representing a good average of a given size for fitting trials. Their feet were measured using methods similar to those in volume and orthopaedic trade. Trial shoes from Clarks' current range were selected, of similar design to those used in orthopaedics. Both shoes and their lasts were available from stock. Observer tests were carried out and fit was assessed by the developed shell shoe method. This research also contains innovative techniques for fit assessment and pioneering work to establish normative data and techniques. Most of the experiments, although conducted with normal volunteer subjects, are directed towards orthopaedic footwear.

ACKNOWLEDGEMENTS

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Last but by no means least, a very special thanks must go to **Mrs. Daphne Warren** who has helped me by proof reading this thesis.

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CORRIGENDA

Page	Para.	Line	Description
77	3	13	replace *Hi-Tech* with **advanced technology**
82	1	5	replace *match* with **approximate to**
85	2	3	should read ...the **actual foot shape.**
122	1	4	should read ...at least **3 iterative loops** on...
124	2	1	replace *adopted* with **developed**
154	2	5	should read ...the **indications are that the shells method could** also be...
216	1	1	should read ...the **ball of the last** on...
216	1	2	should read ...the **ball of the foot** further...
225	2	14	should read ...fitted or acceptable **degree of looseness,** soon...

CHAPTER 1
INTRODUCTION

1.1 Background of the research

This research focuses on last design and manufacture. The last provides the basic shape around which the shoes are made. In turn, the shape of the last is derived from the foot. Therefore the shape of the last is fundamental to footwear. Accurate foot measurements are needed to achieve a better last shape which should result in a well fitting shoe. This important relationship takes on an even greater importance in the case of orthopaedic footwear.

This particular research will concentrate on the assessment of shoe fitting factors and on the relationship between foot and last shape and is intended to benefit the footwear industry both in the volume and orthopaedic trades. Moreover, it is hoped that this study, conducted in the UK will also stimulate orthopaedic footwear research and development in Taiwan. It is part of a larger project, SELECT[1], in the Department of Medical Engineering and Physics (ME&P), at King's College School of Medicine and Dentistry (KCSMD) in London, covering investigations into an integrated design and measurement system[2].

Relationship between shoe last shape and foot shape:

"*The shoe last shape must be the shape of the foot...*" So said **Dr. Ellis**, a foot doctor, according to **Plucknett (1922)**. If this reasoning was to be accepted there would be no difference between the shape of the last and the foot. However, no one with

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[1] EUREKA PROJECT EU661 titled "SELECT -- Feasibility and definition of integrated measurement, data-bases and computer aided design for orthopaedic footwear", which brings together medical researchers and specialist orthopaedic footwear companies from the United Kingdom and the Netherlands.

[2] The trial results of this study may be published under the terms of the EUREKA partnership, i.e. publication must be agreed in advance with the project coordinator and must respect commercial confidence.

shoemaking experience thinks of taking a plaster cast of a foot and making a shoe on it, as replicating the foot shape does not usually produce satisfactory footwear. Firstly, the foot cannot be said to have a single shape: this varies in different positions when sitting, standing and walking. The last surface is then smoothed in contrast to the bumpy foot shape (eg. the toes).

Additionally, after a particular dimension of the foot is measured, this actual measurement is not always reproduced on the corresponding last. Sometimes the last is made deliberately larger or smaller, and these "last allowance" (dimensional differences) are normally according to facts and the last-maker's experience. For example, the last is made longer than the foot to accommodate the foot extension during weight-bearing and walking. The last girth can be made smaller to prevent the foot from slipping forward.

In 1934, Mr. **H. Bradley**, the president of BTRA[3] (Boot Trade Research Association), posed the key questions about the relationship between shoe last shape and foot shape is "*What are the necessary and sufficient conditions that a shoe last shall fulfil in order that it may be suitable to a particular foot; and how do these necessary and sufficient conditions change according to the type and class of footwear under contemplation?*" According to the **Crafts Council (1979)**, "*we have never really found an answer to the question of the relationship between the shape of foot, last and shoe*". Measuring the foot more accurately will go some way towards resolving this problem but it is not the complete answer because there are a number of uncertainties and unknown factors within these shape relationships which it is hoped this research will help to explain.

In June 1965, Dr. **Clinton L. Compere**, who was the President of the AAOS (American Academy of Orthopaedic Surgeons), forwarded a letter to the National Footwear Manufacturers Association[4] (NFMA), warning that "*...the proper shoes must cover the foot, conform to the foot, complement the foot, but never compress the foot...*".

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[3] The forerunner of the SATRA (Shoe Allied & Trade Research Association) Footwear Technology Centre.

[4] The forerunner of the American Footwear Industries Association (FIA).

He also stated that some foot problems and deformities are man-made, with the greatest single factor in creating them being a shoe that is improperly made or fitted or both.

Footwear has always been assumed to be largely responsible for forefoot deformities and problems. For example, the shearing stresses (or torsional stresses) commonly occur in the tissues of the feet because of movements **within** the foot and **between** the foot and shoe where they are in contact. These mechanical stresses, however, are usually combined into complex stresses which in excess cause the tissue trauma and result in corns, calluses, bursitis, blisters, etc (**Adams, 1989**).

Based on the results of the American Orthopaedic Foot and Ankle Society Women's Shoe Survey[(Frey, et al.,1993)], a total of 356 normal female subjects (aged 20-60) with no history of diabetes, rheumatoid arthritis, previous foot trauma or foot surgery were trialled to evaluate the deforming effects of improper-fitting shoes on normal foot. About 80% of the subjects had some foot pain mainly in the toe (58%) or/and ball (27%) regions. The authors indicate that the wearing of shoes influences normal foot function and leads to unusual stresses on the foot. The results above suggest that shoe shape is the essential extrinsic factor which affects the development of forefoot deformities, however, the fact remains that there are many individuals ie. 20% of the subjects[(Frey, et al.,1993)] who wear high fashion shoes and do not cause any foot pain and problems.

Figure 1.1: THE FOOT MODELS WITH AND WITHOUT SHOE WORE, WHICH ARE TAKEN FROM THE SAME FOOT.

In addition, according to **Sim-Fook & Hodgson (1958)**, a small percentage (*1.9%, n= 107 pairs*) of unshod feet still developed hallux valgus and other forefoot deformities. Moreover, the fitting department of C&J Clarks provides an interesting photograph (**figure 1.1**) to show the difference between the shape of the same foot either bare foot or in well-fitting shoe. The compression of the foot in plan view is evident, particularly in the forefoot region. It arises from any two converging forces. In the case of the toes, the interdigital surfaces must be frequently compressed.

These indicate that there must be some unknown intrinsic factors which enable to make the feet vulnerable to cause or prevent the feet from such problems. Although it is still not clear which designs of shoe are most liable to lead to the foot disorder, it is recognised (**Hutton & Stokes, 1991**) that hallux valgus and hammer-toes are associated with the wearing of the improper-fitting shoes. If these factors are kept in mind, the requisites necessary for the design of proper fitting shoes can be worked out. Shoe last shape, forming as it does the foundation of the shoe industry, is of paramount importance.

Although a last is based on a foot shape, its shape must differ from the foot, and the extent and nature of these differences depends upon a number of factors and their derivative sub-factors, all of which influence the dimensions of the last shape in varying degrees. **Figure 1.2** shows the factors which must be taken into account to match a last shape to an individual foot shape. These factors are explored in more detail in next chapter.

Before concentrating on the research, it is necessary by way of background to outline the shoemaking processes for volume and orthopaedic trade and explore the history of the footwear industry both in the UK and Taiwan, the Republic of China (the researcher's country).

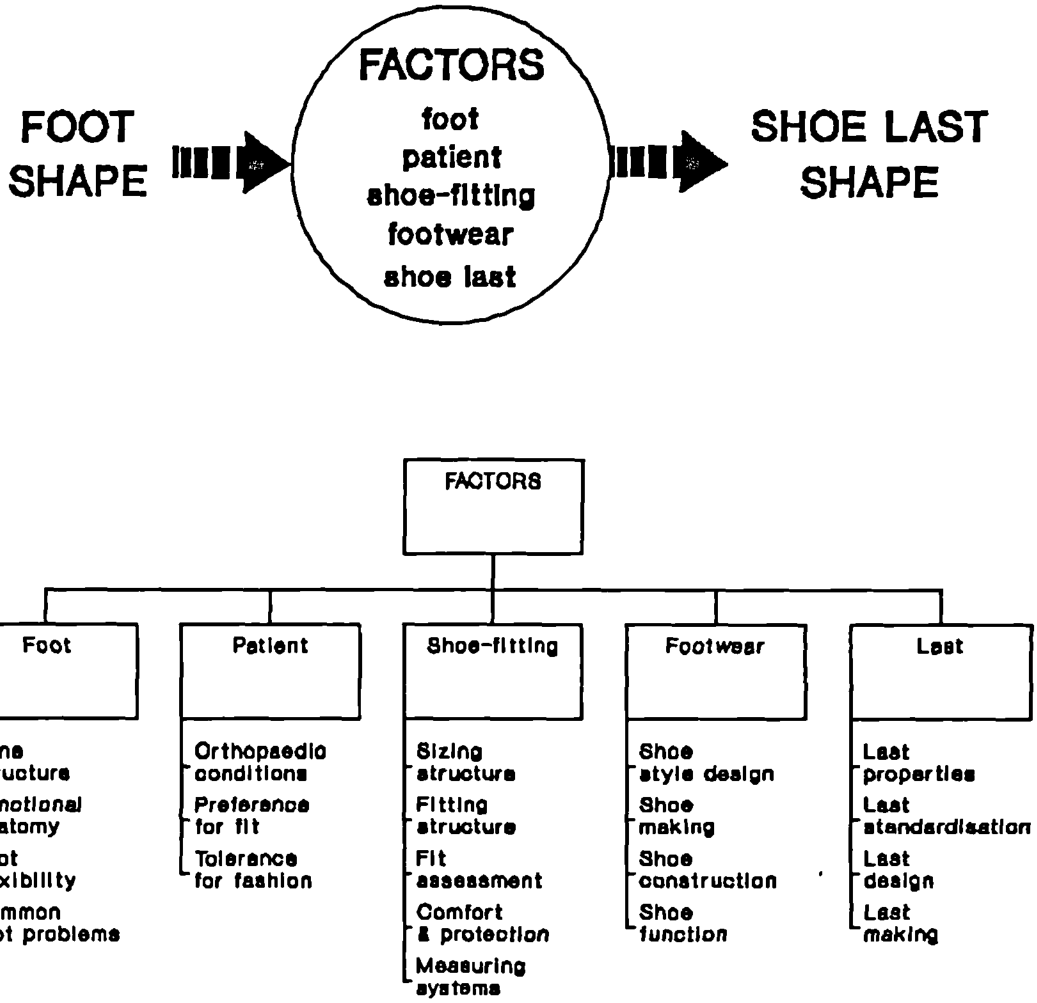

Figure 1.2: FACTORS BETWEEN FOOT SHAPE AND SHOE LAST SHAPE.

Comparison of volume and orthopaedic shoe making

In 1810, Sir **Isambard M. Brunel**, completed the first machine (British Patent No: 3369) ever used for making footwear (**Quimby, 1946**). Then, between 1850 and 1900 (**Rossi & Tennant, 1986**) a series of shoe machines were invented which vastly increased production speed and sharply reduced the price of the shoes, and the shoemaking processes were also changed soon after.

Before shoe machinery was extensively used, all shoes were made entirely by hands. There was no obvious difference between volume shoemaking and orthopaedic shoe making. As the use of machinery increased, however, the different requirements became apparent.

(1) In volume shoe making, the lasts are pre-made and they are graded from a standard model, which is made to fit the majority. Before shoes are made, a fitting trial with a group of notional subjects is required to ensure that the corresponding last produces shoes which fit. During fitting trial, it is not necessary to take any special measurements. All one has to do is to measure the length and girth (width) in order to match the size/fitting of the standard last. The shoe last design and making for orthopaedic patients is different from that of the volume trade. It requires more skills and greater accuracy in foot measurement; also better knowledge of foot problems (eg. foot disorders, etc.) and skill in shoe-fitting techniques are of importance.

(2) Fashion style is the first consideration in volume shoe making, whereas for orthopaedic footwear, it is the function style which is important. The low-heeled lace-up style (eg. Gibson or Oxford style) is always the ideal first choice in orthopaedic footwear because the facing gap can provide a better fitting and the topline of the shoe can be fixed firmly. However, it is quite often the case that thé patient with foot deformities may also be handicapped in other ways (Holmes, 1980). For example, he may have stiff or fused hips, limited spinal flexion or impaired used of the fingers and hands, which prevent him from tying laces. Therefore, consideration must be given to alternative styles of fastening.

(3) Orthopaedic footwear is usually hand made rather than machine made. In volume shoe making, the shoes are machine-made and travel by a production route (see *Chapter 2* for details). The shoemakers usually assemble a routine operation which is only one step of the shoemaking processes eg. clicking (cutting), closing (stitching), etc.

(4) In the UK, orthopaedic footwear is divided into two groups (Hughes, 1983); **ready-made footwear** (ie. made on extra depth and/or extra width lasts) and **made to measure footwear** (ie. nominally the same as **bespoke**, but is commonly used to denote shoes made on a stock last which corresponds approximately to the measurements of the customer's foot). For ready made orthopaedic footwear, the processes are similar to

those used in volume shoe making. For orthopaedic made to measure footwear, special skills are required (**BS-5943, 1980**). The BS-5943 specifies the basic methods for taking and recording of the feet necessary for the manufacture of the orthopaedic footwear. These skills are relevant to both volume shoemaking and orthotics.

Historical developments in the footwear industry:

Volume footwear: The UK footwear industry has been established for hundreds of years, and has become renowned world-wide for its high quality **British styled shoes** (eg. Oxford, Derby & Brogue styles). It enjoyed marvellous growth in the international footwear trade around the period of the World War II, and reached its peak in the 1960s. In Taiwan, the Republic of China, the footwear industry was set up only about 30 years ago but it grew and developed amazingly fast, with Taiwan gaining the nickname of the **Kingdom of shoemaking** in 1970s.

Unfortunately, good things do not last forever. Over the past decade, the footwear industry in both countries has been facing the difficulties of fierce competition. In the UK, it is impacted by low cost imports and the gradual loss of its' home market. In Taiwan, it is under pressure from low labour cost competitors eg. mainland China and Thailand, and is losing its international markets rapidly. Both countries are battling against adversity and trying to recover their markets for the future.

Orthopaedic footwear: In the United Kingdom alone, an estimated 70,000 pairs (**Lord, 1989**) of special orthopaedic shoes are made each year for patients with foot problems ranging from congenital deformity to arthritis. Based on a survey of the orthotic services in England and Wales (**Bowker et al., 1992**), there is a very high numbers and costs in **FOOTWEAR** items, which represent about **62%** of all orthotic prescriptions and about **56%** of the total annual NHS orthotic expenditure (ie. 68 million pounds). An estimated cost of 38.4 million pounds relates to orthopaedic footwear.

In the past few decades, Taiwanese shoe manufacturers have produced hundreds of million pairs of shoes every year but regrettably not a single pair has been specifically made for an orthopaedic patient nor has any attention been paid to the problems of foot care. The cause of this can be traced back to the past two decades when the economy developed rapidly, but the welfare work of health and social security was completely ignored.

Belatedly, last year a new governmental organisation, **Taiwan Footwear R&D Institute**, was set up to bring the Taiwanese footwear industry out of decline. In addition, a **National Diabetes Tracing & Service Centre** is planned in Taiwan to provide a necessary and comprehensive service for diabetic patients (**Department of Health, Executive Yuan, 1991**). Excitingly, orthopaedic footwear R&D is supported by both bodies. It should be the first step towards the orthopaedic footwear in Taiwan. Needless to say, such a plan cannot be completed overnight. The only way of reducing the risks and increasing the likelihood of success, is to transfer learning and technology from the experienced countries such as the UK, Germany and Netherlands.

1.2 Taiwanese perspective

The government of the Republic of China came to Taiwan in 1949, four years after the end of the World War II. At that time, Taiwan was primarily an agricultural society. The first priority of the government was economic development. By 1971, Taiwan was successfully transformed from an agricultural, import-oriented, debt economy to an increasingly industrial, export-oriented, surplus economy. Today, Taiwan has become one of the newly-industrialised countries of the Western Pacific. At the end of 1991, the population stood at 20.6 million with a GDP[5] per head at over US$ 10,000 (Economist, 1992).

The footwear industry, one of the earliest industries to be successfully transformed in Taiwan, has continued to develop since the 1960's and it is now the top 4th largest industry in terms of Taiwan's foreign trade, falling behind only electronic, textiles and machinery (Taiwan Economy Research Centre, 1991). During its development, low labour costs, sufficient and diligent labour, accompanied by the success of various rubber and plastic products, has led the Taiwanese footwear industry to gain advantage despite extreme international competition. Since 1976 it has gradually become one of the biggest shoe suppliers in the world, although in 1990/91 417 million pairs of shoes were produced, of 800 million pairs only half the total produced in 1986. In the face of this decline, Taiwanese shoe manufacturers are changing to better quality production with higher profit margins to allow for higher costs. In order to upgrade the related footwear products and maintain advanced competitive ability and prevent the decline of the industry. Since 1987 many outstanding footwear participators eg. designers, engineers, and researchers have been selected by the government and sent to the UK and Germany to absorb high quality footwear technology and knowledge.

Because Taiwanese footwear industry is export-orientated (ie. exports represent over 90% of the total footwear products) and lack of design and market developing abilities, most footwear manufacturers rely on foreign buyers to provide style samples with model

[5] GDP: The gross domestic product which is the total value of all goods and services produced domestically by a nation during a year. It is equivalent to gross national product (GNP) minus net investment incomes from foreign nations.

lasts, a typical OEM[6] industry. Although Taiwanese footwear manufacturers have improved their techniques and productivity over a long period of time, without research and development, it is possible that the last industry would gradually lose their ability to design and make model last. As can be imagined, this is also a major hindrance to the upgrading of the Taiwanese shoe industry.

Moving from volume footwear to orthopaedic footwear trade, it is worth considering the diabetic foot as an example of a foot problem because it is one of the main foot pathologies requiring orthopaedic footwear. The prevalence of diabetes in England and Wales has been estimated at 500,000 which is about 1% of the UK population (**Neil et al, 1986**). In Taiwan, according to data from The Survey of Taiwanese Epidemiology (**Department of Health, 1991**), residents have a 1.73% chance of developing diabetes. Therefore, there are an estimated 350,000 diabetics. This major disease is on the increase and is now the 5th place in the list of top ten fatal diseases (**Central Daily News Taiwan, 1993**). An official report from the **Department of Health (DOH), Executive Yuan** (1992), Taiwan, R.O.C., pointed out that in 1992, 235.6 persons per million died of diabetes, compared with 205.8 in 1991, a rise of 14%. In 1980 there were just 64.9 deaths per million (ie. a rise of about 300% in last decade). It is the highest rate of increase amongst the top ten dangerous diseases in Taiwan.

Williams (1985) conducted a survey of diabetic patients admitted to hospital in East Anglia, UK. Extrapolating from this survey approximately 20% of these diabetics have foot-related problems. Using the **Williams'** percentages, every year about 70,000 of Taiwanese diabetic patients may develop foot-related problems. Undoubtedly, diabetes is leaving a large number of patients in need of special orthopaedic footwear. However, this serious health problem is also a valuable opportunity for orthopaedic footwear development, presenting a brand new area of study for the R&D work in Taiwan. As seen at the beginning of this chapter, this challenge is one to which Taiwan is responding.

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[6] OEM: Original Equipment Manufacturing, which means that products are made by customising basic parts supplied by others. Also called as MTO (made to order).

Based on the researcher's observations over a 10 year period and his experience of the footwear industry participator, the priority will be to maintain the high standard of research and development, and to provide footwear for orthopaedic patients taking into full consideration of their comfort, well-fitting, and safety.

1.3 Aims and objectives of the research

The purpose of the research is to investigate the key factors of shoe fitting and foot measurement, which relate to shoe last design and manufacture. The area of study is also related to the development of a computer-aided design (CAD) system for orthopaedic footwear.

The objectives of the research are

- To review the relevant literature concerning the subject areas both in the volume and orthopaedic trade, relating to shoe last, the foot, and footwear.
- To investigate into the level of knowledge in the footwear and related industries to report on the levels of recognition of the relationships between foot measurement, last modelling, fashion & orthopaedic styling, and the fit & comfort of footwear.
- To investigate the differences between the selected stock model last, its made to measure last, and the foot from a normal subject in order to recommend the last allowance for future development and upgrading the quality of footwear products.
- To generate procedures and assess strengths and limitations of assessing the different contribution of the last shape and shoe construction factors on shoe fit by using shell shoe method.
- To identify the limits of tolerable last allowances in order to define the required allowances for last design and manufacturing.
- To investigate aspects of foot shape changes under conditions of weight-on and weight-off, standing and walking.
- To evaluate the possibilities of applying all the results to the patients who require orthopaedic footwear prescriptions, and draw conclusions.
- To identify the requiring further research.

1.4 Methodology

1.4.1 Documentary research

A general literature search related to the subject areas has been undertaken, and background information on foot & foot problems, last & footwear design, orthopaedic footwear, and CAD/CAM, etc. is reviewed in chapter 2. Due to the lack of newly published books relating to last design and manufacturing, much of the materials in these areas are obtained from older text books and reference books.

1.4.2 Interviews and visits

The lack of up to date published material in relating to last design and manufacturing, it has been necessary to visit the shoe and last manufacturers in order to gain a better understanding of the production processes and standard model last design and making techniques both in the volume and orthopaedic trades. Consultations and interviews with specialised last designers and last making experts from the last factories and experienced lecturers in footwear design in De Montfort University. Some related research centres and manufacturers were also visited (see *Appendix 1-1*).

1.4.3 Framework development

A series of informal visits to experienced engineers and technicians, and discussions with supervisors were first carried out. These resulted in the modification of the area of inquiry and the identification of additional informants or sources of information.

This research consists of four experiments; (1) last made to measure (custom modification), (2) shell shoe fitting[7], (3) joint girth fitting and tolerable allowance and (4) measurement of in-shoe foot length and toe room allowance. In **figure 1.3**, a framework is given to illustrate the research structure and the relationship between chapters.

[7] Shell shoe fitting: The fit is assessed on a basis of a shell shoe which is made by vacuum moulding suitable PVC (or EVA) materials over the last to form a temporary shoe.

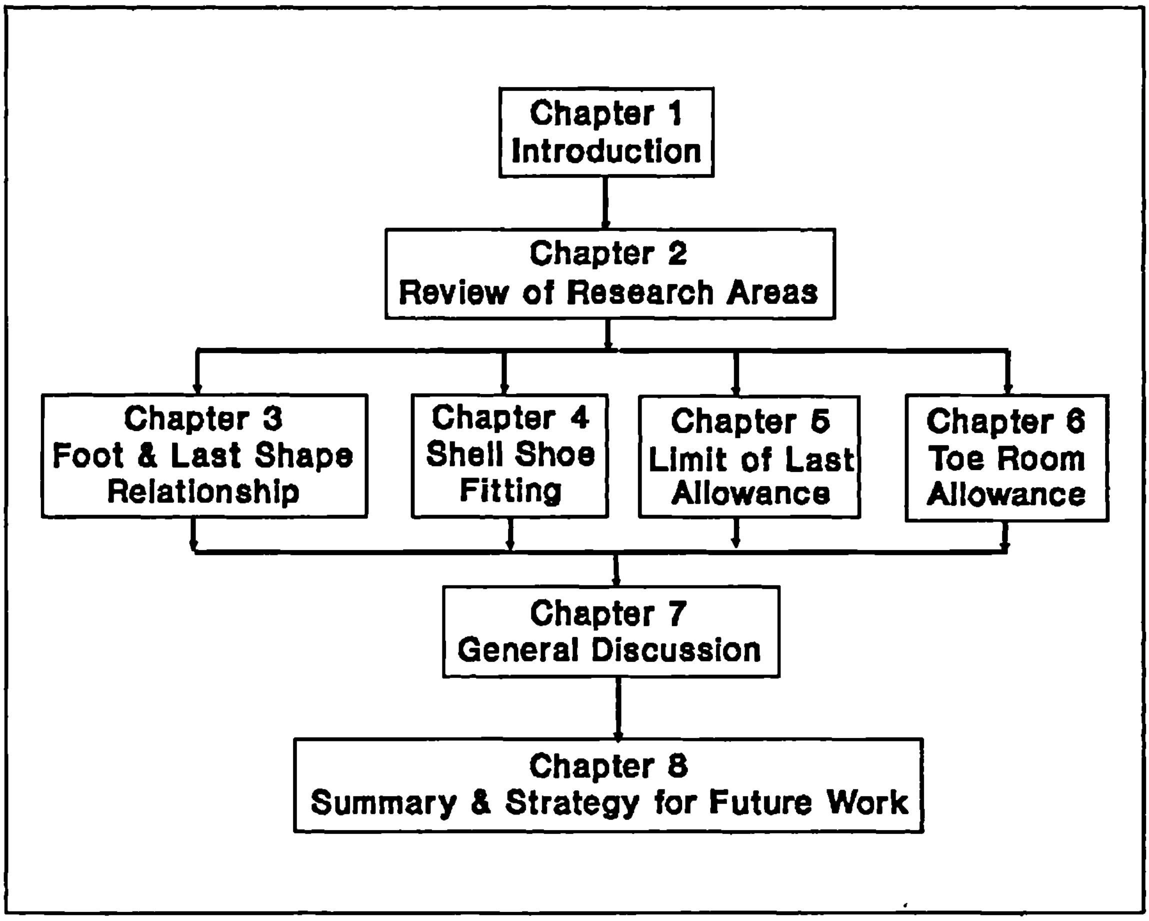

Figure 1.3: THE FRAMEWORK OF THE RESEARCH.

Following the introductory chapter 1, chapter 2 gives a brief review of the basic concepts concerning feet and foot problems, the literature relating to the history from shoe to last and their properties. There is an introduction and a comparison of the three existing foot measurement systems used in the UK footwear industry: British Standard BS-5943 system for the orthopaedic trade; C&J Clarks' measuring system for the purpose of fashion shoe fit assessment; and the SATRA foot measuring system for footwear R&D. The differences between these foot measurement systems are outlined and discussed. Also, covered in this chapter are the sizing and fitting systems; orthopaedic footwear style cutting rules and the CAD/CAM systems for footwear.

In chapter 3, firstly, a method for research into and development of model lasts which can be used to represent the method of shoe last assessment is introduced. Then a sample foot is compared with its made to measure last and the selected stock last model in order to illustrate the similarities and differences. The latest developed 3-D digitisers are adopted to take the cross-sections of the foot and lasts accurately and automatically. This study will support and identify the differences between the foot and its made to measure last, and between two lasts.

Chapter 4 presents a procedure for solving the problems of the mis-fit by using a special shell shoe fit assessment which has been reported by **Lord & Chen (1992).** It was observed that shell shoe fitting is universally used in the Netherlands, but not at all in the UK. This trial is conducted to determine the limitations of fit assessment from shell shoes. First, a suitable foot measurement system is developed. Preliminary intra-observer and inter-observer methods are undertaken for testing the operating consistency and discrepancy, and then a number of usual fitting trial volunteer subjects' feet are measured. Four designs of standard sensible shoes with lace-up fastenings and low heels were selected from C&J Clarks stock, and the shell shoes are constructed over the corresponding lasts. The fit of both the shoes and shell shoes is then assessed and the results compared. Shell shoe fitting has several advantages. The shoe need not be constructed before fit assessment is undertaken, which reduces both the cost and delays in achieving the final shoe. Also, the fit factors due to last shape can be separated from those due to shoe construction. Since transparent, the shell shoe provides the facility to assess fit visually and better information forms the basis for any re-work required rather than feed-back on the upper of the shoes.

In chapter 5, the limits of tolerable last allowances at joint regions are investigated. In this experiment, a number of techniques are used ie. foot measurement, shell shoe making, style cutting, fit assessment skills, last assessment and duplicating skills. First, the 5D model last of   is selected which refers to the shell shoes fitting results. Five different girth fittings of same notional last (B to F fittings) were graded and produced. Special walking shell shoes are made using EVA material to assess the fit of the joint regions. By analysing the measures and fitting results, the limits of the tolerable last allowances can be identified. Also, girth allowances for last R&D can then be recommended.

The purpose of chapter 6 is to develop a length measuring device which is used for measuring weight-bearing and walking allowance of the foot length. This research will provide an accurate inside shoe measured allowance on the changes of foot length during sitting, standing, and moving. Therefore, the maximum effective foot extension, which is also the minimum toe room allowance of the foot, can be suggested for the last design and manufacturing processes.

It is crucial for these systematic experiments in chapter 3 to chapter 6 to adopt the criterion for orthopaedic footwear in order to ensure that the whole procedures of the methods are available for application to orthopaedics from the results of normal subjects' trials. In respect of this criterion, all the trialled shoes and lasts are selected from stocks, which are of similar design to those used in orthopaedics, eg. low-heeled shoes with fastening over instep region, and both shoes and their lasts are available from stocks. Also, feet are measured by using methods similar to those used in both the volume and the orthopaedic trades.

In chapter 7, many results from those trials undertaken which are related to each other are analysed and discussed. Chapter 8, the concluding chapter, a summary of the research findings are given. Following that, the remarks and suggestions for further research are outlined.

1.5 Related work

SATRA footwear technology centre[8] has been doing research in shoe and last assessment for several years. A number of experiments and reports have been published recently. However, under the conditions of their conservative and confidential principles, it is quite difficult to get the information which is related to research work in this field. In the SATRA Bulletin, **Bayes (1988 & 1989)** reported about the method of assessing last fit by using computer; **Browne (1981 & 1988a)** suggested a guidance for shoe fitting trials and he also introduced a new instrument for assessing fit.

Similarly, most research work on the foot and last have also been conducted by SATRA, and all of these foot surveys are commissioned by their members, the results of which are withheld for commercially sensitive reasons. A pilot survey of foot measurement was undertaken by **Chao (1989)**, which involves sampling 100 male subjects with ages ranging between 18 and 31 in UK, and the measurements of foot were recorded on traditional measurements of length, girth and height, which is purposed to investigate the UK shoe last industry and identify key factors related to last design and production techniques which are relevance to the upgrading of Taiwanese footwear industry.

Many groups have worked on CAD and scanner systems to approach the surface shaping of orthopaedic foot and last (**Tuckman et al, 1992**); **Lord et al., (1991)** reported and concentrated on the technical evaluation of a commercial shoe CAD system, which is already widely used in the volume shoe trade, to access its ability for orthopaedic shoe upper design. It is the first time that the commercial CAD are encouraging for its potential use with orthopaedic shoes and lasts successfully. Also, an interactive computer graphics system for the design of moulded and orthopaedic shoe lasts was introduced by **McAllister et al (1991)**. Other commercial developments are noted but no publications reported.

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[8] SATRA: Shoe and Allied Trades Research Association, now known as the SATRA Footwear Technology Centre. It is an inter-national centre of shoe technology research, with headquarters and laboratories at Kettering, Northampton, UK.

Since 1991, an international research project "SELECT" (EUREKA, EU-661), in the Department of Medical Engineering and Physics, which is purposed into feasibility and definition of integrated measurement, data-bases and computer-aided design for orthopaedic footwear. This project brings together medical researchers, specialist and orthopaedic footwear companies between the United Kingdom and the Netherlands.

CHAPTER 2
REVIEW OF RESEARCH AREAS

2.1 Feet and foot problems

The well-fitting and comfort of the foot is always the first concern for most of people when buying footwear. For this reason, before designing and developing a last, it is necessary to understand a little about the human foot and the way in which it grows. At birth the skeletal framework is predominantly cartilage but centres of ossification already exist. Ossification of different bones takes place at different times and over varying periods. During the early months of inter-uterine life the skeletal system of the limbs has been mapped out in cartilage. As the process of growth continues, some of this cartilage is slowly transformed into bone (see *Appendix II-I* for the timetable of ossification). Therefore in the early stage the foot is highly malleable. This is important for two reasons:

- it allows some congenital deformities to be corrected more easily.
- it also means that the feet may be deformed by premature or abnormal stresses.

2.1.1 Bones in the foot

It is extraordinary that in such a small area there are 26 bones in each foot, as illustrated in **figure 2.1**, and these are in three groups; tarsus, metatarsus, phalanges. Moreover, there are two small bones under the first metatarsal head (the distal part which articulates with the phalanges) and these are known as sesamoids. Sometimes others are present elsewhere in the foot, but since their presence, position and size vary so much, they are not included in the main 26 bones.

(1) Tarsus: The tarsus is where the larger, bulkier bones are clustered. It consists of seven bones. The biggest bone at the rear of the foot is the calcaneus (also called the heel bone). On top of the heel bone, it is the talus, which connects to the leg. In the anterior part of the talus is the navicular, a boat-shaped bone, and little lower down,

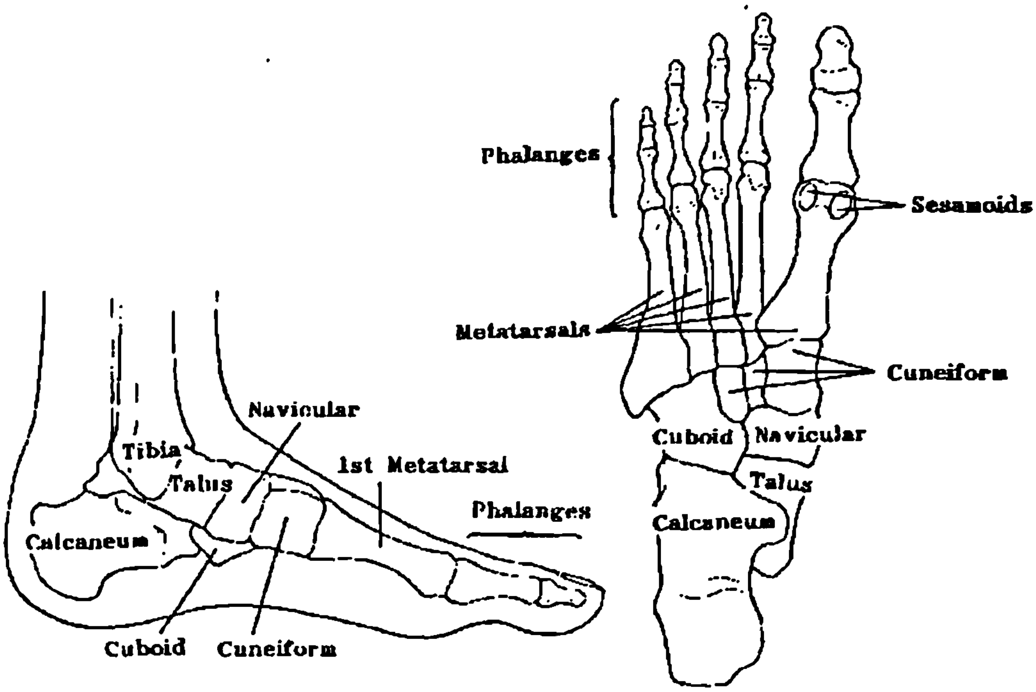

Figure 2.1: BONES OF THE FOOT.

toward the lateral side is the cuboid which joins the calcaneus. There are three cuneiforms in the front of the navicular.

(2) Metatarsus: The metatarsals are the longest bones in the foot. Five metatarsals articulate with the tarsus and comprise the proximal part of the forefoot. There are wide spaces between these metatarsal bones to give them room to spread a little when weight is borne on the foot. Thus this section also serves in a limited way as a shock-absorbing structure. The 1st metatarsal bone is on the medial and the 5th on the lateral side of the foot; the second metatarsus is the longest one. The rounded forepart of these metatarsal bones, called metatarsal heads, are in contact with the ground. These comprise the ball (joint) of the foot and form what is known as the anterior (transverse metatarsal) arch.

(3) Phalanges: There are fourteen toe bones in the phalanges (or toes). The big toe (also known as the hallux) has two phalanges, whereas the other four lesser toes have three phalanges each.

2.1.2 Functional anatomy

The human foot is a complicated mechanism which can be simplified into two separate basic functions. Firstly, the foot serves as a support or a bracket to keep us balanced when standing still. Secondly, it works as a lever to move the body forward.

Normally, in standing, the weight of the body is transmitted by the lower limb and applied through the ankle to the posterior part of the foot at the head of the talus. Then from the surface of the talus-head, the force rests on three areas of the foot i.e. heel (the posterior support), 1st metatarsal-head (the anterior and medial support) and the other four metatarsal-heads across the ball of the foot (the anterior and lateral support).

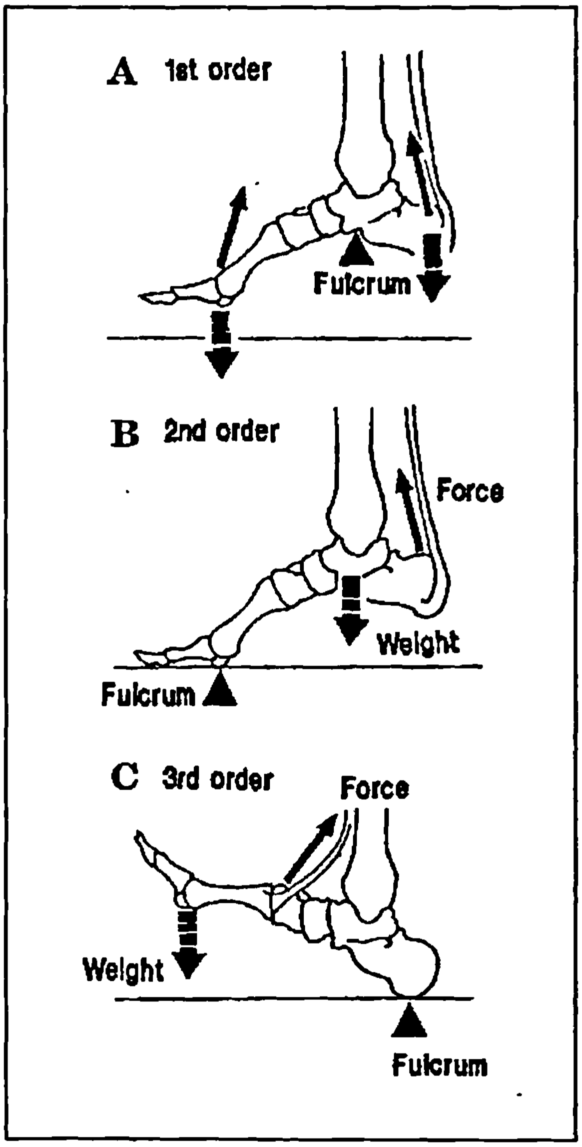

Figure 2.2:
LEVERS OF HUMAN FOOT.

During movement, the bones of whole foot act as stable levers. Levers are divided into three different types, the classification depending on the relative positions of the force, weight and the fulcrum. Many examples of levers are to be found in the human foot. For instance, when the foot is raised, the ankle joint is the fulcrum, the resistance is the ground, and the force is applied by the muscle attached to the back of the heel. **Figure 2.2(A)** shows that the foot acts as the 1st order of lever (ie. where the fulcrum is between the force and the weight). The 2nd order of the foot lever (ie. the weight is in middle) is illustrated in **figure 2.2(B)**, when rising on tiptoe, the fulcrum is at the end of the toe, which is the metatarsal-phalangeal joint. The weight of the body to be raised is applied at the ankle joint and the force is again applied to the muscle at the back of the heel. When the heel is kept on the ground and the toes raised, we have an example of the 3rd order of the lever of the foot. **Figure 2.2(C)** shows that the heel is now the fulcrum, the force is applied by the muscles of the front of the leg and the weight is the toes.

2.1.3 Common foot problems caused by footwear

Accurate diagnosis is not usually based on a fixed procedure of analysis and practical examination but on specific investigation of the patients' subjective complaints. **Hoppenfeld (1976)**, an American foot surgeon, who commented that a diagnosis can be made on the basis of the patient's history and supported by a precise, specific physical examination. Especially in the case of foot, the anatomy is relatively accessible to palpation[1] and specific testing. The foot is one area in which the subjective complaints of the patient are often vital clues that lead to the correct diagnosis. Most of the complaints relate to pains in the forefoot such as hallux valgus, hallux rigidus, swelling and redness on the 1st and 5th metatarsal-heads, and on the top of toes (claw toes and hammer toes). These might be caused by continually wearing a pair of shoes with insufficient width (or girth) and lack of enough accommodation at the forepart region. Some of the patients who suffer from problems in the instep or waist of the feet do so as a result of birth defects (congenital defects) such as flat-feet and high-arch feet. It is very difficult to find a pair of shoes to fit them. In the case of congenital defects, proper custom-made fitted footwear is usually required to improve foot comfort. Sometimes, the complaints of pains are at the heel might be also caused by a tight shoe or irritated by the backpart stiffener (eg. heel counter) in a shoe especially at the back heel height and under ankle height.

2.1.4 Factors in footwear fitting

Heel to toe and heel to ball: Shoes are marked in length and width. At the shoe shop, all the fitter needs to do is measure the length and width to find a pair of shoes which

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[1] Palpation: examination by touch. (esp. medically)

corresponds to the marked size and fitting. In fact, two measures of length and width alone are not enough to ensure a pair of shoes fits the feet properly. There is a measurement called heel to ball (heel to joint), which can prove a useful measurements in fitting. In **figure 2.3**, both A and B have the same heel to toe length but different in heel to ball lengths. The "*" shows the position of the ball joint (1st metatarsal-head). The heel to ball measurements can be taken using a proprietary measuring device such as **"Brannock gauge"** (see **figure 2.4**).

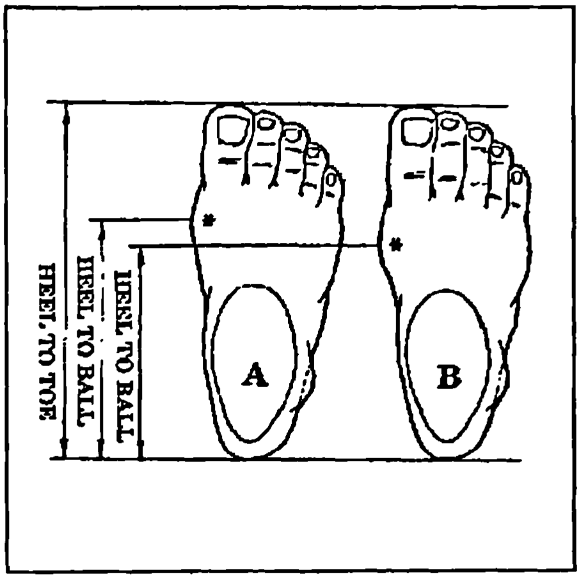

Figure 2.3: HEEL TO BALL MEASUREMENT.

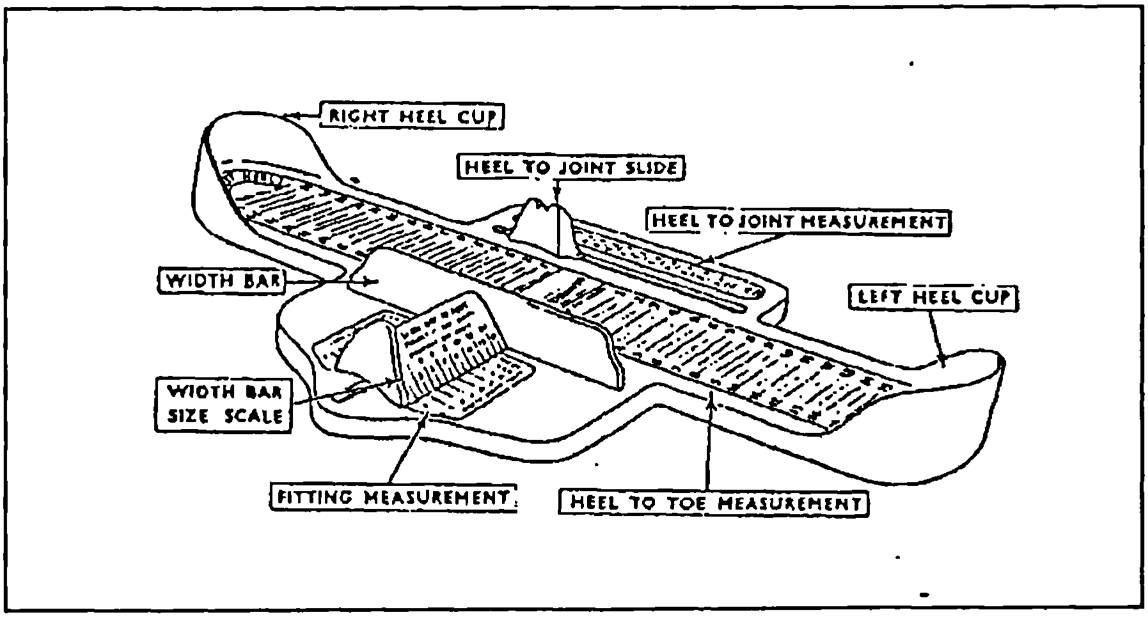

Figure 2.4: THE BRANNOCK MEASURING DEVICE.

The Brannock has three different measurement scales ie. children's, adult males (for boys and men) and adult females (for girls and women). This device measures for overall foot length, heel to ball length and ball width.

Shoes must fit correctly in heel to ball, and should accommodate the ball joint in the widest part of the shoe. In walking, as we know, the feet flex across the ball of the foot. Shoes are designed to bend just forward of the front edge of the shank called tread-line[2]. The bend in the shoe must match the bend in the foot, otherwise the foot will be forced to bend in the wrong place of the shoe.

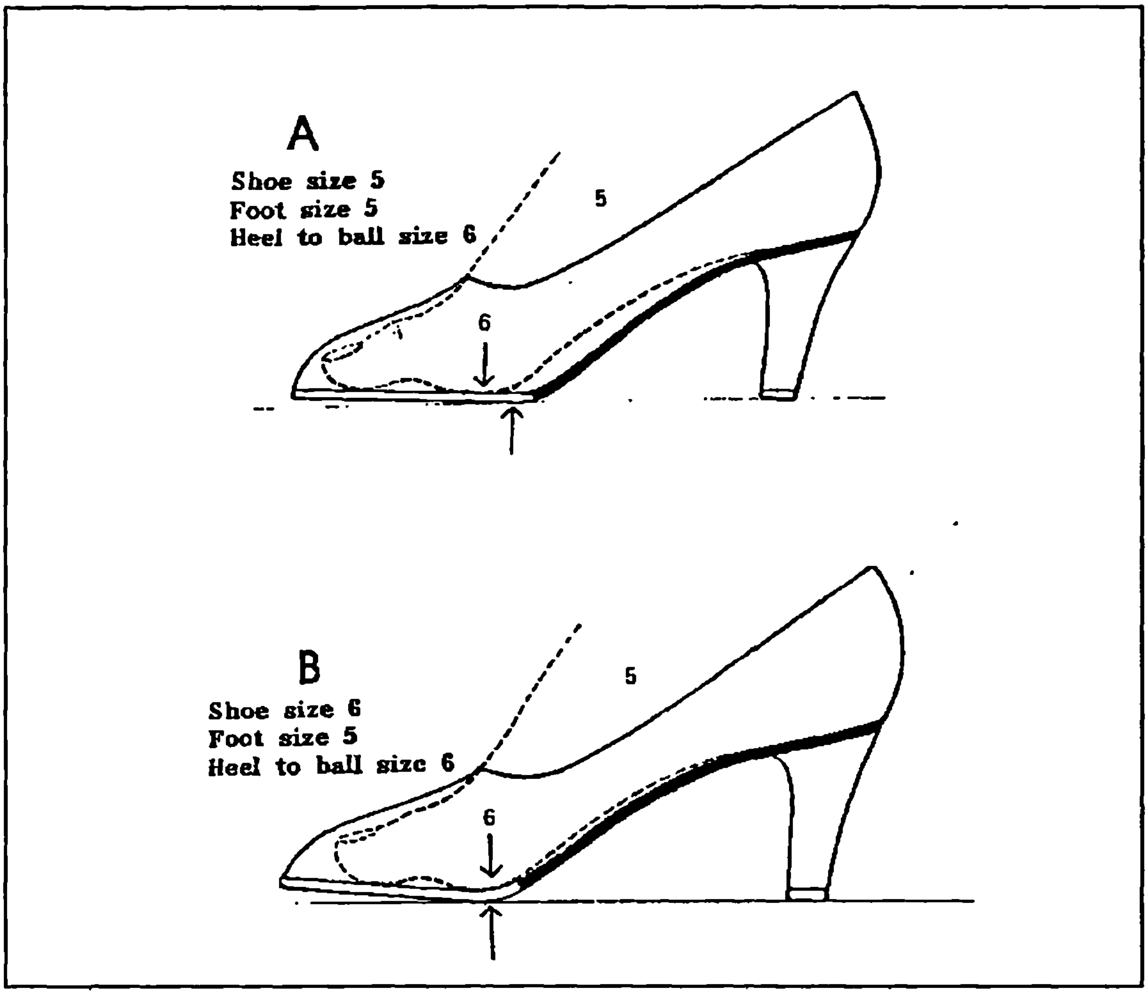

Figure 2.5: FITTING A LONGER ARCH. (FROM HARDY, 1988; WITH PERMISSION OF PUBLISHER)

Figure 2.5 shows a size 5 foot length with the heel to ball size 6 i.e. a longer than average arch with shorter toes (in diagram A). In terms of overall foot length, a size 5 shoe would be enough but the arch would be under stress from the body weight and receive no support from the shoe. In diagram **B**, a size 6 shoe would give a better fit

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[2] Tread-line: A line across the forepart-bottom of a shoe that is generally in contact with the ground.

and more support, although there would be more length than required and a narrower shoe (in joint width) or one with a lower heeled shoe may be necessary to prevent the foot sliding forward.

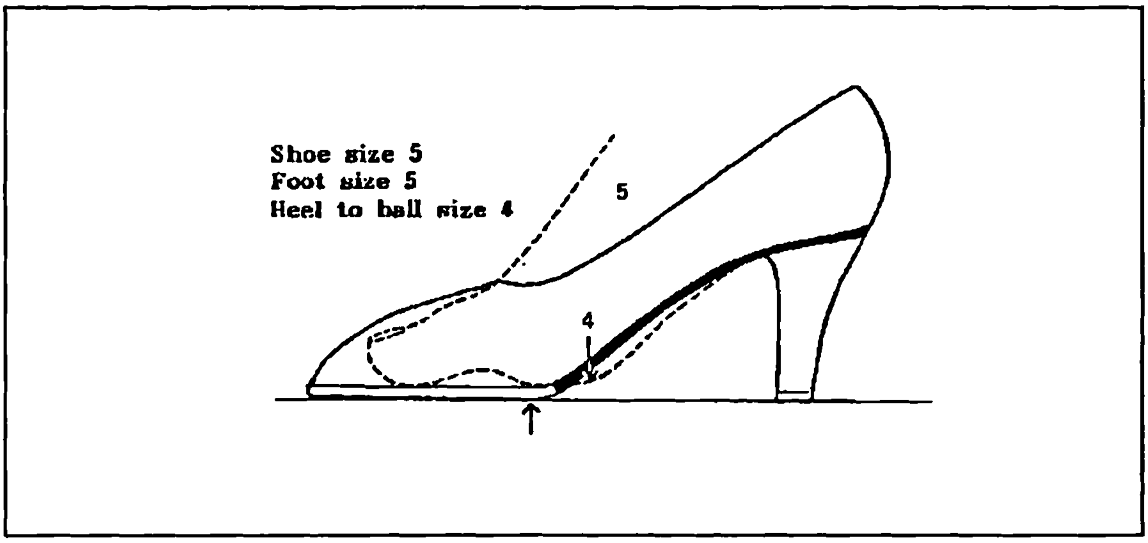

Figure 2.6: FITTING A SHORTER ARCH. (FROM HARDY, 1988; WITH PERMISSION OF PUBLISHER)

If the foot length is size 5 and the heel to ball measurement is size 4 (indicating a shorter arch with longer toes), this can create a problem at the plantar surface of the foot from the rigid shank of the shoe. The foot obviously requires a shoe with sufficient length for the toes to operate but if the ball position is behind the tread-line it is difficult for the foot to move correctly and during walking the shank can cause discomfort (see **figure 2.6** for the details). The shoes selected should therefore have greater flexibility; for example, a moccasin, or for women, an open-toe or a sling-back style, both with a lower heel if possible.

Potential footwear problems:

Pointed-toe shoe: Originally, the pointed-toe segment was intended to be a false, styled toe-piece and was not meant to contain the foot. The addition of this type of styling into footwear is only for fashion or aesthetic appearance; it can do nothing to assist walking or comfort. It makes the foot painful and may create skin abrasions, corns, swollen bursae, tendinitis by cramping the toes into the end of the shoe.

Chisel last shoe: In this type of footwear, the vertical height of the toe-box is diminished in the shape of a chisel. The toes can easily be compressed from above and this may result in skin abrasions, tendinitis.

High-heeled shoe: Fashion styling of the heel of the shoe has been going on for many years. The higher the heel pitch, the shorter[3] the foot looks. When wearing high-heeled shoes, the feet cannot function effectively. Therefore, the shock of weight bearing cannot be dispersed evenly over the whole foot and all the weight of the body rests on the metatarsal-heads. Compression of the toes can easily create hammer and claw toes, in-grown toenails, corns, abrasions etc.

Platform shoes: The platform shoe is elevated with cork filler. Such shoes were originally worn to prevent the feet from getting dirty and make the individual feel taller. The wearing of a platform shoe thoroughly destroys the biomechanics of normal gait because the style of shoe does not allow the foot to bend naturally. This situation can be rectified if the toe-spring of the shoe is improved. Platform shoes also make balance difficult, shock the foot joints and increases the danger of falls.

Footwear problems relating to materials:

Non-breathing materials: Leather is still the most "breathing" material for shoes. A shoe made of non-breathing materials may cause problems for the skin and foot discomfort such as skin maceration, athletes foot and fungal infection.

Un-yielding materials: Shoes made of un-yielding materials, such as plastic, tend to rub the foot. It is not easy for such a shoe to conform to the shape of the foot.

2.1.5 Comfort

Many people speak of shoe comfort but the meaning of this is quite difficult, because shoe fit itself is a subjective judgement of the consumer's feeling. From the point of

[3] With high heel, the foot looks 1-2 inches shorter, compared with a flat or low heeled shoe but this is really an optical illusion.

view of fit, there is an common belief that if the shoe fits correctly, comfort automatically follows. However, this is not necessarily true, as shoe comfort involves much more than proper size and fit. To select comfortable footwear, the following factors have always to be considered.

(1) Proper fit: It is obvious that the shoe size must conform to the foot size, not only simply to foot length and joint girth (or width) but also heel to ball length, heel, topline, etc. The proper fit means a correct dimensional mating of foot and shoe throughout the whole shoe.

(2) Flexibility: Shoe flexibility mainly refers to the flex action across the ball. In taking a step, the flexion of the bare foot across the ball is about 50-60 degrees at the maximum angle (**Helfet et al, 1980**). From the point of view of comfort, the footwear should flex at the ball easily (ie. correspondence of position of flex axis) and with the same degree of flexion as the bare foot.

(3) Upper materials: There are some elements of shoe upper materials that determine the shoe comfort ie. conformability, breathability, shape retention, textile, weight, suppleness and softness.

(4) Construction: Shoe construction determines the structural integrity of the shoe components and its assembly methods. It also determines the retention of the shape (or dimensional) stability of the footwear during wearing.

(5) Under foot resilience: The foot receive an average of 8,000 step-shocks a day (**Rossi & Tennant, 1984**). A cushioned buffer zone between foot and non-resilient sole or ground brings about a completely different feeling of under foot comfort.

Both shoe fit and comfort are involved in the functioning of the foot. Obviously, because footwear is made in quantity, its dimensions have been fixed and settled once and for all at the time of manufacture by the shoe last, on which it was made. The foot is just the opposite; it is a very much alive, changing and moving physical part which is connected to other moving parts. The foot is a tool designed for walking. A shoe which, in the standing position may seem to be the right size, shape and fit, may nevertheless during walking fail to provide the expected comfort. The dynamic factors (ie. tread, gait patterns, perspiration, foot balance and foot injury) can always affect the static factors of fit assessment, causing discomfort.

2.2 From shoe to last

The first shoe of which there is a record **(Herbert, 1920)** is a sandal-like structure that consists of a sole woven only from plaited water-softened reeds or grass which was fixed to the foot by rawhide thongs, as illustrated in **figure 2.7.** These sandals are now on display in the United Shoe Machinery Ltd. (USM) Building, Boston, Massachusetts, USA., where there is a wonderful collection of ancient and modern shoes. The sandal was unearthed by an explorer in the Fayum district, southeast of Cairo, Egypt, where the civilization was at its height about 2000 B.C.

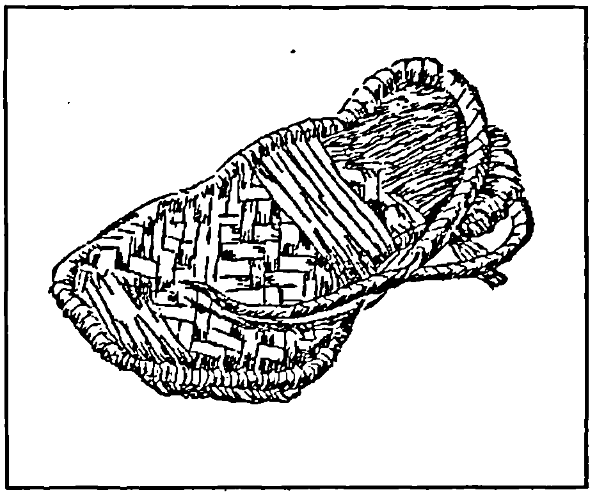

Figure 2.7:
REPRODUCTION OF SANDAL MADE FROM THE LEAVES OF THE PAPYRUS PLANT, CAIRO, EGYPT, ABOUT 2000 B.C. (SOURCE: QUIMBY, 1946)

By 1500 B.C., sandals were in common usage. The pictures carved and painted on the temple walls of tombs in the ancient Egyptian City of Thebes show ancient shoemakers at work at their low benches around c.1495 B.C., at the time of the exodus of the Israelites **(Leno, 1949)**. These tell us that shoes were made from the leaves of papyrus and rawhides and worn by Egyptians and the inhabitants of other middle eastern countries, over three thousand five hundred years ago.

The earliest shoes were measured from **footprints** of the person who was to wear them. When making shoes, only the imprint of the foot in dampened sand was needed by the ancient shoemakers to measure the size. Other ancient peoples simply wrapped feet in animal skins or other materials, which were then pulled over them like bags and fixed to the ankles with drawstrings in order to protect feet from the weather, thorns, sharp-pointed rocks, etc. Then, some shoemakers discovered that by chiselling the rough shape of an entire foot out of stone, they could make shoes even when the customer was not available for a fitting. Hundreds of years later, shoemakers found an easier way to get the shoe-shapes they required was by whittling blocks of wood (**Severn, 1964**). These were called "**LASTS**".

2.2.1 Last definitions

First of all, it is necessary to define what the term "last" means. **Quimby (1946)** explained that

> The last is a reproduction, generally of maple wood, of the approximate shape of the human foot. A properly constructed shoe, when made over this form, will provide foot support and foot protection without undue pressure, binding or constriction at any point. The last, therefore, as the very foundation of the shoe, carries a great responsibility: upon it depends the fitting qualities, the walking ease and the stylish appearance of the finished shoe. Because of this the making of lasts is a most important factor in good shoemaking.

The word "last" comes from an old Anglo-Saxon word "laest" (**Severn, 1964**) which means a "footprint", a "foot-track", or a "foot-trace". The French call it "forme", and the Germans use the word "lasten". Nobody knows exactly when the first "last" came into use. It can be proved from recorded evidence that a wooden last was found dating from the Neolithic Period in Switzerland (**Waterer, 1944**) and the British Museum preserves another from Khadalik in Turkestan, dating from the seventh to eighth century. It has also been reported (**Thornton, 1958**) that a number of Romano-British iron cobbling lasts have been found in several places in the United Kingdom.

2.2.2 Last specification and production

(1) Last specification: **Figure 2.8** shows the reproduction of the approximate shape of the human foot and over this form a shoe is shaped (**AFMF, 1970**). In modern last making, a standard model last is still made by hand. This embodies all the dimensional and shape requirements. (There are a number of definitions associated with lasts specified in *Appendix II-II*).

(2) Last production: The last making depends on different types of demands. For example, bespoke (or designer), volume production and orthopaedics are the three main different purposes for last making. In spite of these different demands, they share the same first step ie. the making of a standard model last, which is similar to the bespoke method as follows:

Bespoke shoe last making: A bespoke last is not always made from a new one but is often adapted and reproduced from an existing last model, which is selected from stock closely related to the required shape. The last is then re-shaped, mostly by the addition of layers of materials such as leather, cork, fabric tape, or plastic patches (e.g. EVA[4]).

Last making for volume shoe trade: The first step of last production in the volume trade starts with the making of a hand-made model (as in the bespoke method), which is always made of wood. This is then used to produce a range of sizes (or fittings) on a copy lathe machine, which can duplicate a pair of lasts at the same time.

Last making for orthopaedics: There are three types of last making required in the orthopaedics, ie. plaster casting last (A type), made to measure shoe last (B type) and ready made extra depth shoe last (C type). The making of orthopaedic bespoke last is the same as the normal bespoke method described above. Sometimes, the plaster cast method is very similar to the bespoke method but it is necessary to take a plaster cast of the whole foot as the basis for the last and then re-shape it to be a last.

Recently the extra depth shoes have become more popular with the orthopaedic patients and their fitters. The shoes for orthopaedics can be made in advance so the patients need not wait for a long time to get their shoes fitted. More and more high street styles can be adapted and transferred to the orthopaedic lasts. The extra depth shoe lasts are made by a similar method to the volume shoe trade but averaged measurements are taken from the orthopaedics.

[4] EVA: Ethylene Vinyl Acetate, a kind of hard-foaming plastics.

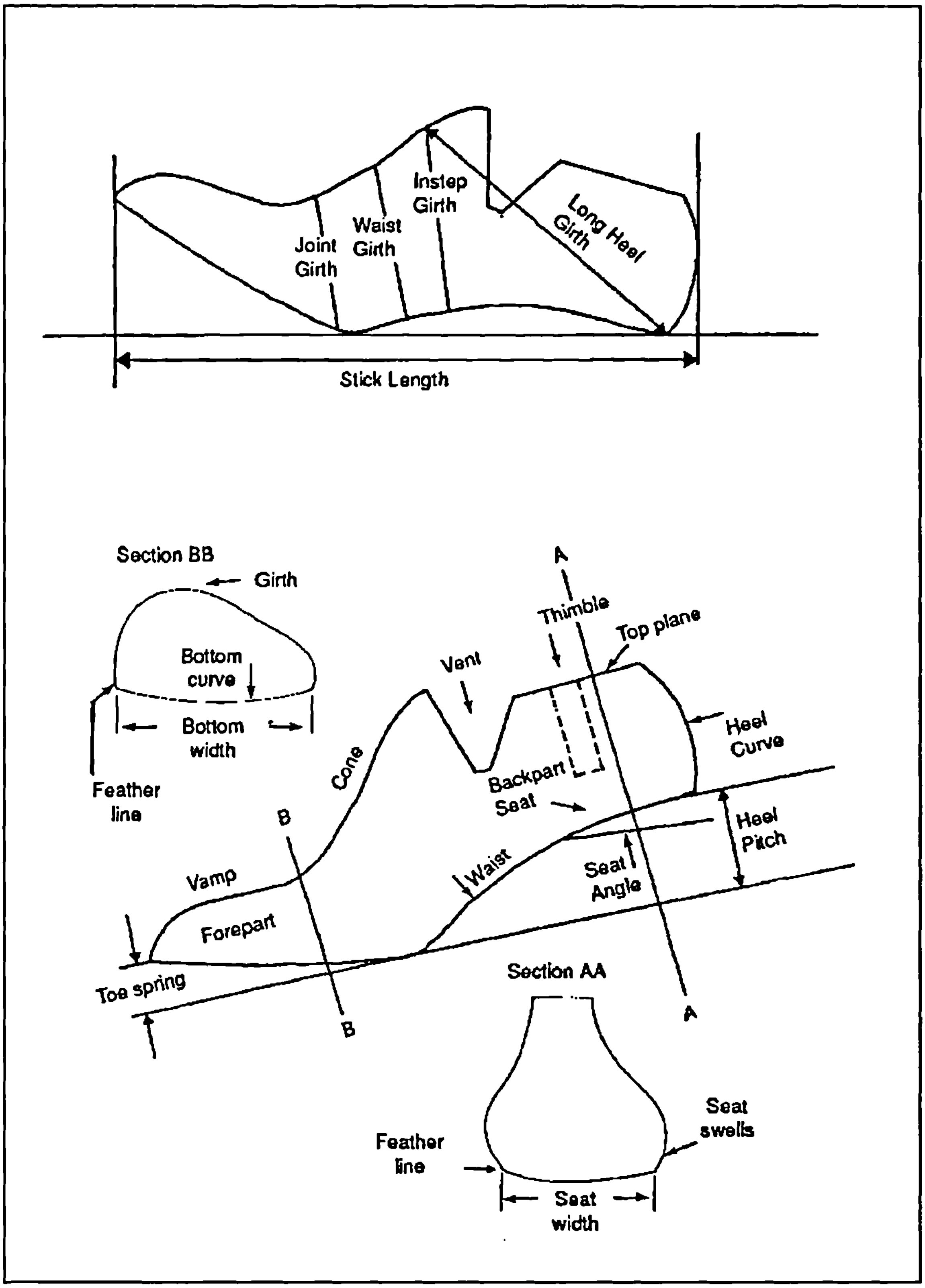

Figure 2.8: THE SPECIFICATION OF LAST MEASUREMENT AND THE LINK HINGE LAST SHOWING VARIOUS FEATURES. (SOURCE: A.F.M.A., 1970)

2.2.3 Last properties

(1) Standardisation: Many companies aim at some degree of standardisation, the main reasons being to provide a consistent product and a basis for the grouping of sizes and shapes in order to reduce the number of individual components needed. Standardisation would result in the components of the last being cheaper and able to be ordered well in advance; also the design or operation of shoe machinery would be simplified. In addition, the quality of shoes should be improved because of some in-built functions, which would enable the last and its components to be well-matched. The joint-line[5] divides a last into forepart and backpart. The former is always affected by the fashion trends or the special demand for toe shape and so it is unsuitable for standardisation. In contrast, the backpart represents a more functional region of the shoe and is not particularly affected by fashion. Therefore standardisation is usually confined to the back of the last behind, the joint-line.

(2) Toe spring: Toe spring is the vertical distance between the ground and the toe point of the last. It is important because it helps progression in walking. The raised toe of the shoe offers some resistance to the downward pressure of the toes of the foot, resulting in a state of leverage at the ball of the foot. Factors such as heel height, shoe style, upper and sole material, sole construction and the general flexibility of the shoe, would have their effect on the degree of toe spring required in a last. The higher the heel, the less toe spring is required to compensate for flexing: a high-heeled shoe needs to flex less than a low heeled one. Toe spring in the last has reference to and is regulated by the rigidity of the footwear. SATRA gives the recommended data for toe spring in a variety of shoe styles (see **table 2.1**). Despite the fact that the higher the heel, the less the toe spring required, a senior expert in model last design and making, Mr. A. Weston (Mobbs Miller Ltd.) pointed out that most model last designers and makers have been simplifying the toe spring from varying flexibility to a single value of **8 mm** (about the diameter of a pencil).

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[5] Joint-line is a line which passes through the joint break point and across the ball of the foot.

TYPES OF FOOTWEAR		TOE SPRING
MENS	light footwear(sandal, plimsoll, etc.)	9 - 14
	heavy footwear	14 - 20
WOMENS	walking shoes	7 - 14
	high-heeled shoes	6 - 10
BOYS	light footwear(sandal, plimsoll, etc.)	6 - 11
	heavy footwear	9 - 14
GIRLS	light footwear(sandal, plimsoll, etc.)	6 - 11
	walking shoes	7 - 12
These data are only intended as a general guideline.		

Table 2.1: TOE SPRING FOR FLEXIBLE FOOTWEAR.
(SOURCE: SATRA BULLETIN)

(3) Heel pitch: The heel pitch relates to the height of heel, and has its effect on the characteristics of lasts. It mainly affects the fashionable appearance and style. Once established, the heel pitch cannot be changed.

(4) Twist: Twist (also called **Curve** in American footwear) in a last is the relative transverse position between the heel-seat[6] and forepart. If the heel-seat is rotated towards the medial side from the forepart central line, the shape is said to be twisted (curved). On the other hand, if the heel-seat is moved towards the forepart central line, the shape is made straighter.

(5) Materials: The material of the last should be hard and stable to give footwear its shape. There are three materials which are used for last making at present, metal, plastic and wood. Metal lasts are made from aluminium. They can withstand high temperature and pressure. Most vulcanised and injection moulded shoes use metal lasts. The majority of current lasts are made of plastic (polythene) which is not only tough and light-weight, but also by its very nature hard and stable. It is an ideal material for mass

[6] Heel-seat: The bottom surface of the heel end of the last, where the heel lifts are attached.

produced lasts. However, for ease of shaping and repairing and its ability to withstand temperature changes, wood is the best material to use for hand-made model last making.

2.2.4 Supply of lasts and shoe-manufacturers

There is no such thing as a staple or stock last made up in advance for when it might be needed by the shoe manufacturer. Lasts are only made **"on order"** to suit the shoe manufacturer's need. Many large shoe manufacturers have 30 to 60 last styles in use with 80 to 90 sizes and fittings in each style, representing a total of 2400 to 5400 different lasts, and to produce shoes in volume, many pairs of lasts are needed in each style, size, and fitting (**American Footwear Manufacturers Association; AFMA., 1970**). Furthermore, all last manufacturers have to face greater variations in their production schedules from time to time because of the varying production demands of the shoe manufacturer.

Last makers still create individual models of lasts for making shoe samples, and these shoes are made and tried on selected feet for fit and appearance. Often many changes must be made and a number of lasts are discarded before a shoe manufacturer approves one and places it on the production line. Therefore, it can be appreciated that long-term planning is necessary to prepare for new styles.

Nowadays, most of us walk in comfort, because of the experience and technical expertise of last makers. They provide the basis for well-built, properly balanced, and scientifically sized footwear. Therefore, close co-operation between last-makers, shoe manufacturers, and shoe machinery companies is important for the continuing development of the world footwear industry.

2.3 Footwear

"What is a shoe?" The word "shoe" is derived from an old Anglo-Saxon word "sceo", which evolved into "schewis", then "shooys", and finally "shoe". All meant the same: A shoe is basically a **foot covering (Rossi & Tennant, 1984)**. However a sock or stocking is also a foot covering, so we cannot say that "foot covering" and "shoe" are a synonymous. Obviously, a shoe is much more than merely a foot covering. Therefore, some special factors are required to define and identify the purpose of a shoe.

Protection: The shoe protects the foot against cold and heat, abrasion and injury, soil and grime, hard or rough ground surfaces.

Wear: A shoe is an article of utility to perform various tasks in a service sense.

Comfort: A shoe is designed to be worn with satisfaction and comfort, without distress.

Functional performance: A shoe is designed and constructed to comply with the foot's special functional requirements under dynamic conditions.

Foot health: Through its design and construction, a shoe can contribute towards the maintenance of healthy feet.

Aesthetics: A shoe is a decorative article to satisfy the wearer's preference.

2.3.1 Anatomy of shoes

The **top** and **bottom** are the two major parts of the shoe. The top, also called the upper, is a portion of shoe which covers the upper surface of the foot and consists of the vamp and the quarter (for a complicated style it could include extra parts such as counters, appliques, fastenings, linings and ornamentations). The vamp lies between the toe cap and the quarters. It covers the toes and forepart or front of the shoe, and consists of one or more pieces, depending on the style of shoe design. The quarters are the portions of the shoe which cover the back of the foot. Usually they joined together at the backseam, and are reinforced by the stiffener. The bottom, also called sole unit, may consist of welt, insole (inlay), middle-sole[7] (midsole), outsole, runner[8], bottom-

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[7] Middle-sole is an intermediate sole situated between the insole and outsole. Usually to be found in sandals, boots, safety boots and heavy walking shoes.

[8] Runner is the name given to the insole of a sandal made by the **Veldtschoen** (also known as **stitched-down**) construction. (source: Miller, 1980)

filler, heel, heel-lifts[9] and top-piece[10] (also named top-lift). The details of the shoe's anatomy and parts are illustrated in *Appendix II-III.*

2.3.2 Footwear manufacture

Generally speaking, shoemaking includes 3 stages: design, making and construction.

Shoe design: At the stage of designing a shoe, it is necessary to make a decision about the style of shoe which will be produced. From this information, a model last is made. At the same time while the required last is being made, the desired styles are being designed. After approval, these styles are converted into patterns. A number of samples would be made and tested for suitability in relation to the material used, capability of mass production and the fitting qualities required.

Shoemaking process: (also see *Appendix II-IV*)

Volume shoe making: In volume shoe making, the shoe travels by a production route (rooms or departments) as follows

(1) **Material store:** This is a place which receives the upper leather, bóttom leather and all the other materials from which the shoes are made. Then, these materials are issued to the clicking room (cutting room).

(2) **Clicking room:** These materials ready classified are cut up by clickers who will have been supplied with the correct patterns by the pattern engineers. When all the various pieces of the patterns (both uppers and bottoms) have been cut, the upper parts will be passed to the closing room. The bottom parts (ie. outsole units, insoles and other items required for the bottom of the shoe) will be sent to the lasting & making room where the upper and lining are drawn tightly over the last and attached to the insole and the bottom is prepared for attaching to the uppers.

(3) **Closing room:** This is where all the separate upper parts are sewn together to form the complete uppers. Many refinements are completed at this stage eg. folding and

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[9] Heel-lifts are layers of material such as leather or leatherboard which are built up together and shaped to form the built-up heels.

[10] Top-piece is the layer of leather on a heel which touch the ground.

finishing the edges of the materials, applying perforations and decorative stitching, inserting hooks and eyelets. The uppers then enter the lasting & making room.

(4) **Lasting & making room**: During this stage, the uppers and bottoms are joined together. Firstly, the upper is lasted in separate operations such as toe lasting, side (waist) lasting and heel seat lasting. Then the outsole unit is attached onto the bottom of the lasted upper. This is the first time the shape begins to look like a shoe.

(5) **Finishing room**: Here the last is pulled-off the shoe. During this stage, also, special finishes are applied such as colouring, cleaning, polishing, pairing or other treatments designed to make the completed shoes look fresh and attractive.

Orthopaedic shoemaking: In the UK, the orthopaedic footwear is divided into two groups (**Hughes, 1983**); ready-made footwear and made to measure footwear. The making of orthopaedic footwear requires special skills (**BS-5943, 1980**), relevant to both volume shoemaking and orthotics.

(1) **Foot assessment**: The first and most important step is to assess the foot (ie. to obtain sufficient information about the deformities from the patient). A plan outline diagram of the foot is made and with the foot still in position, four circumferencial girth measures are taken. These measured positions are marked on the outline diagram.

(2) **Measurements**: Girth measurements are taken at the joints, waist, instep, and long heel girth. An additional short heel girth (for boots making) should be taken, plus circumferencial measurements around the ankle (at the level of the malleolus) and around the leg at the level of the top of the boot. The following measurements should also be recorded: the overall length of the foot (using a size stick) and heel to ball length. The height of any other abnormalities, such as clawtoes, prominent bones etc. should be individually recorded on the outline diagram. Any supports required can also be noted at this time with their location marked.

(3) **Plaster cast**: A plaster cast will give a very accurate, 3-D model of the foot and is always used for a seriously deformed foot. When it is necessary to take plaster casts, the measurements and details above should be taken in the same way.

(4) **Last**: From the plaster cast foot model, the orthopaedic shoemaker (or last maker) is able to make a suitable model last either from wood, plaster of paris or expanding hard foam. Wood is the traditional material, usually maple or beech, but hard foam is

becoming more popular as it is easier to shape and lighter to handle. The last should be hinged to enable the shoe to be pulled-off without breaking the back-seam. The shoe last design and manufacture for the orthopaedic patients will be different from that of the volume trade. It requires more skills and greater accuracy in foot measurement and also better knowledge of foot problems (eg. diabetic foot) and skill in shoe-fitting techniques are of importance.

(5) **Uppers**: The choice of the upper materials is vitally important. Consideration should be given to the patient's general conditions ie. age, level of activity, skin condition, and to the particular foot problems (eg. diabetics, prominent bones, local tenderness etc.). Leather is the first choice and the best material for orthopaedic footwear. An active man with minor foot deformities might require a shoe made of a fairly stout calf leather, whereas a patient with rheumatoid disease and associated deformities needs a much softer leather upper such as glace, suede, or foam-lined leather.

(6) **Style (fastening)**: It is worth mentioning that the style of fastening for orthopaedic footwear is very important. The lace-up is always the ideal first choice in orthopaedic footwear. However, it is quite often the case that the patient with foot deformities may also be handicapped in other ways (**Holmes, 1980**), which prevent them from tying laces. Therefore, consideration must be given to alternative styles of fastening.

(7) **Style (heel)**: The other important factors is the style of the heel. The heel pitch should be of a height to give a balanced, secure, and suitable base. Also, the heel pitch height should be assessed in relation to the general conditions of the patient. Although the lower heeled style (ie. 1 inch) is commonly adopted in orthopaedic trade, sometimes a higher ($1^1/_4$ to $1^1/_2$ inches) or lower ($^3/_4$ inch or less) heel is required.

(8) **Construction (insole)**: A well-fitting shoe is spoiled by an inadequate or improperly designed insole. Currently, the ready made orthopaedic shoes (ie. extra depth) are becoming more popular, as they are made with sufficient depth and width to accommodate most patients' feet. In most case, the need is for an insole that will re-distribute the body weight to relieve the pain and stress.

(9) **Shoe fitting**: It is necessary to assess the fit on the patient before the outsole unit and heel are fitted, so that any minor modifications can then be made.

Shoe construction: The method of shoe construction depends on the method of attaching the sole (both insole and outsole) to the upper, which can vary considerably. The most common ways are

(1) Sewing:

Welted: The upper is attached to insole rib and the welt is then chain-stitched to the rib. The gap (inside the rib) is filled with cork (bottom filler) which gives a flat surface for stitching onto the outsole. The welt and the outsole are lock-stitched together.

Veldtschoen: This is the only one where the lasting allowance is turned outwards (also called the stitch-down method). The allowance is stuck down onto the runner insole. After lasting, the upper and the runner are lock-stitched[11] together, the outsole is then stuck to the bottom of the runner.

Simple veldt: This is a simplified veldtschoen method (usually for sandals), where the upper is flanged outwards and lock-stitched with runner insole. The outsole then stuck onto the already assembled parts.

Slip-lasted: This is well-known as Californian construction. The upper, sock and platform cover are all stitched together. This construction is particularly common for shoes with platform outsole and wedge heel.

Moccasin: The upper and the sole are in one piece, and the shoe is closed by stitching in the vamp.

(2) Non-stitching:

Cemented: The upper is stuck to the insole and outsole with a special adhesive.

Moulded: The moulded construction consists of vulcanised and injection moulded shoes, which are made by the same process. The sole material is injected in liquid form into a mould and the shoe upper is pressed against the mould. Outsole materials are different for these two methods. In the case of the vulcanised moulded shoes, only rubber is used, whereas with injection moulded shoes, Polyvinyl Chloride (PVC) or Polyurethane (PU) is used.

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[11] Lock-stitch: A special stitching method which is to stitch the upper and the runner together completely around the shoe close to the feather edge.

2.4 Foot measurement systems

Feet are measured for a variety of purposes. For instance, a retailer needs to measure feet in order to select suitable footwear to fit the customer; an orthopaedic (or bespoke) shoe-maker requires information about his customer's feet in order that the shoes made for the particular customer will satisfy their fit and comfort needs. In addition, the manufacturers who produce footwear in bulk need to focus their attention on the selection of the market that they seek to satisfy. Therefore, developing satisfactory methods of measuring feet for various demands is very important.

There are three existing foot measurement systems in the UK footwear industry. The first is **BS-5943** system for orthopaedic footwear trade. The BS-5943 standards (**British Standard Institution: BSI., 1980**) specify the basic methods for taking and recording all details of the feet necessary for the manufacture of orthopaedic shoes, especially those required by the last fitter, cork maker, and pattern cutter. The second system is **Clarks measuring system.** C&J Clarks International Ltd., the biggest shoes manufactory in UK., developed its special foot measuring system for the purpose of fashion shoe fit assessment. Finally, **SATRA Footwear Technology Centre** (Shoe & Allied Trades Research Association, Kettering, UK.), the biggest footwear technology research centre in the world, has developed a foot measuring system for use in footwear R&D. The differences among these existing foot measurement systems are discussed in the following sections. (see the *Appendix II-V* for details of the measuring items of these systems)

2.4.1 Required equipment

Table 2.2 shows the equipment required for measuring and recording the foot data, using these three foot measurement systems. A tape[12] is used to take girth measurements of the heel, instep and the ball of the foot, a size stick for the length of the foot (see **figure 2.9**) and a metric height gauge for measuring the height of the foot (see **figure 2.10**). In addition, a properly designed chart is required by all three systems.

[12] The tape is 60 cm (24 inches) long, with 6-10 mm wide, graduated in Metric scales and English shoe sizes on one side and with Imperial scales on the other.

EQUIPMENT	BS-5943	Clarks	SATRA	REMARKS
properly designed chart	*	*	*	*Appendix II-V*
ball point pen or pencil	*	*	*	7mm diameter
metric measuring tape	*	*	*	6-10mm wide
metric length gauge (size stick)	*	*	*	**figure 2.9**
plaster cast taking equipment	*			
drawing frame			*	
metric height gauge	*	*	*	**figure 2.10**
blocks for checking elevations	*			
scriber block		*	*	**figure 2.11**

Table 2.2: REQUIRED EQUIPMENT FOR FOOT MEASURING & RECORDING.

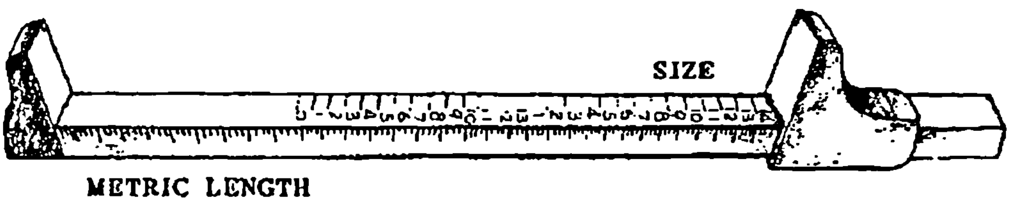

Figure 2.9: METRIC LENGTH GAUGE (SIZE STICK).

Figure 2.11 illustrates a wood block or a metal device named "scriber", in which a ball point pen or pencil is held diagonally with a screw. It is used for tracing round the foot so that the pencil line is exactly the same as the foot contour[13]. This scriber is used by Clarks and SATRA system only, unlike the method of BS-5943, where a ball point pen or pencil is held vertically, a slight thickness being added on the outside because of the radius of pencil.

[13] The point of the pencil comes out exactly at the bottom angle, immediately below the vertical edge which is pressed against the foot as it is moved round it.

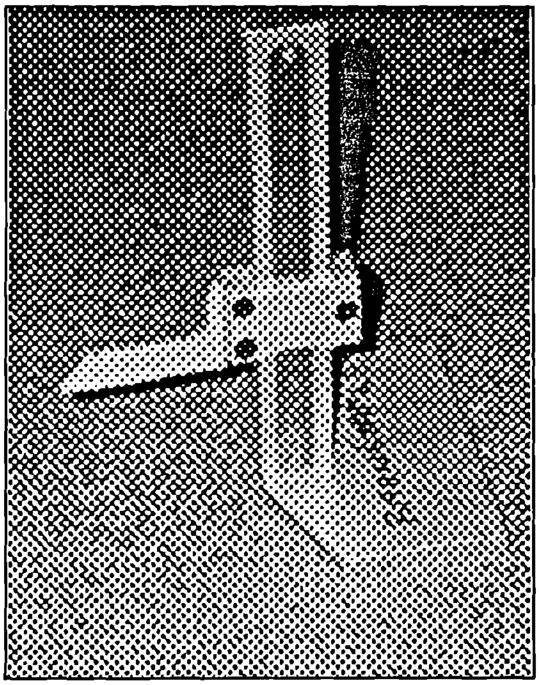

Figure 2.10: HEIGHT GAUGE.

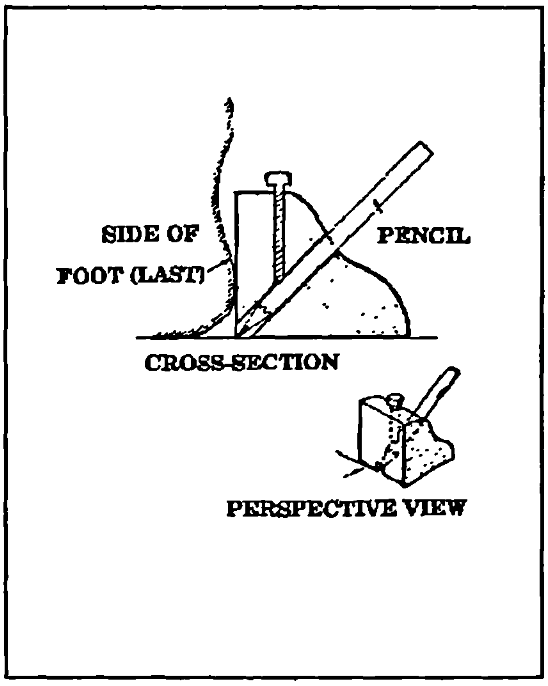

Figure 2.11: SCRIBER BLOCK.

The plaster cast taking equipment and a set of blocks for measuring and checking elevations[14] are used in British Standard methods (BS-5943) for orthopaedic shoes only. There are two typical methods of taking the foot shape, whole foot casts[15] and plantar impressions[16]. The plaster cast is usually taken when the foot cannot be measured adequately by conventional methods; also in the case of an extremely deformed foot where a positive plaster cast needs to be used as the basis of the last in the construction of footwear. Elevations requirements should be measured by orthotists or shoe fitters after consultation with the surgeon. Heel and joint are two of the most important measurements for the orthopaedic patients with extremely deformed feet.

[14] Elevations are the special insert materials which consist of shoe-socks and inserts above the outsoles of the orthopaedic shoes, in order to make up the shorter leg. Elevations may be inside the footwear, outside the footwear or a combination of both.

[15] Whole foot casts: (1) Plaster bandage method which is a complete casting method using plaster bandage which is removed by cutting when dry. (2) Two part or "oyster shell" method embodying plaster slabs, constructed in two halves. (3) Vacuum casting method. (4) Polyethylene sheet moulding method. (see Chapter 3, Section 3.3 for more details)

[16] The plantar impressions: (1) Phenolic foam method. (2) Polyethylene foam method. (3) Plaster of Paris method.

Heel measurement is taken from the centre of the base of the heel (heel-seat), not the extreme back of the heel. The joint measurement is taken from a point directly under the metatarsal-heads. Also a toe measure, usually determined by the toe spring (degree of roll), and an adequate heel pitch measurement are required.

There is a special measuring instrument called "drawing frame", which is a wood plate with one part hinging upwards at right angles to it and both plates are pinned with papers. When the foot is placed on the frame, a outline diagram of the foot is drawn on the horizontal part of paper and a contour of the foot is drawn on the upright section. Although very important for footwear and last shape design, this equipment is not adopted widely except by SATRA.

2.4.2 Measurements

Initial information: All the three systems start with initial foot information taking. For various reasons, BS-5943 system takes more clinical details than Clarks and SATRA do. **Measuring postures:** Weight-on (standing) and weight-off (sitting) position are the two major postures in foot measurement. **Table 2.3** shows the measuring postures in the three existing systems.

SYSTEMS	MEASURING POSTURES	REMARKS
BS-5943	with sitting (weight-off) position	barefoot
CLARKS	with standing (weight-on) position	barefoot
SATRA	both sitting and standing positions	barefoot & hose

Table 2.3: WEIGHT-ON/OFF POSITION IN THREE EXISTING SYSTEMS.

The maximum volume of the foot can be measured in the weight-off position and the minimum in the weight-on position. It depends on purposes of foot measurement. In the case of orthopaedics (BS-5943), the patient's foot should not be compressed, so maximum measurements without any unexpected pressures are required for making the last and shoes. For the fashion shoe assessment of Clarks, subjects are standing and walking all the time, so the weight-on method is usually used.

The SATRA measuring system for footwear R&D is complicated. Both the weight-on and weight-off methods are used. This system takes the measurements of the foot with the subject standing and facing the measurer, barefoot on a flat surface, with the feet slightly apart and body weight distributed equally between both feet, a foot plan of the right foot is then drawn using a scriber block, and the lateral & medial joint and 5th metatarsal-base position marked on the plan (see **figure 2.12** for details of the measurements taken from the foot outline diagram).

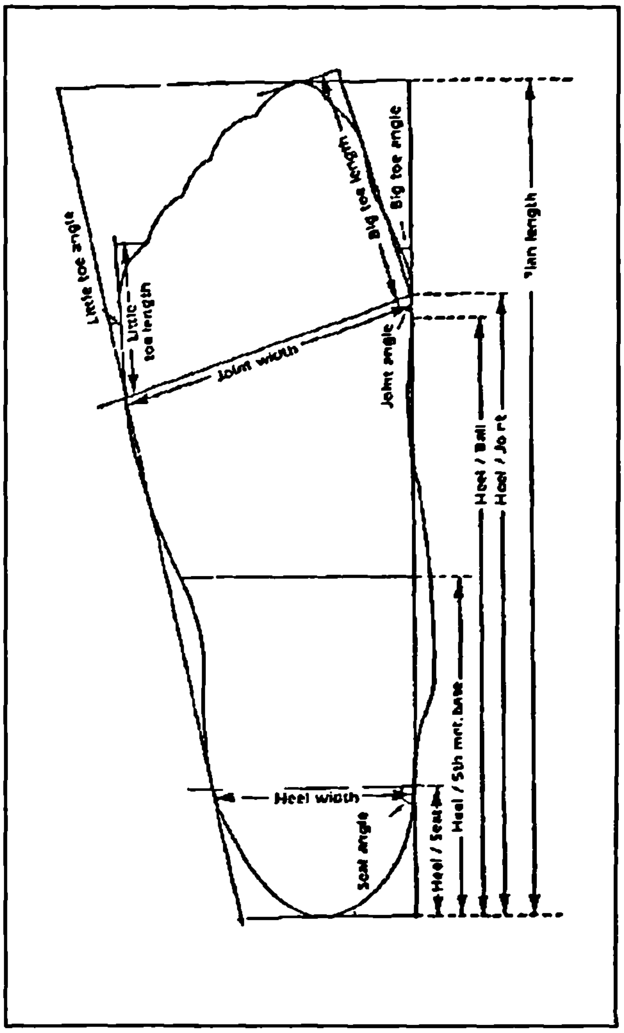

Figure 2.12:
MEASURES TAKEN FROM FOOT PLAN.

The foot of every 5th subject aged 9-16, is measured and the foot outline diagram drawn under special conditions, which are (1) on the right foot with the subjects wearing their own hose, (2) on the bare right foot with the subjects sitting with their feet resting on a flat surface slightly apart at right angles to the lower leg, (3) on the bare left foot with the subjects standing on a flat surface with their feet slightly apart and with the weight equally distributed between both feet. For children under 5, the main bulk of the measurements will be taken in the barefoot weight-off position. The foot of every 5th subject aged 3 is measured in a special way which are (1) with right foot weight-on with/without hose, (2) left foot weight-off without hose.

Measuring items: The main measurements include the length, girth, height, width and angle, the three systems are very similar. **Table 2.4(A)** to **table 2.4(E)** show the different measuring items. **Figure 2.13** illustrates the details of Clarks measuring system, which is sufficient to assess fit for fashion shoes (the marked numbers indicate the measuring items on the diagrams).

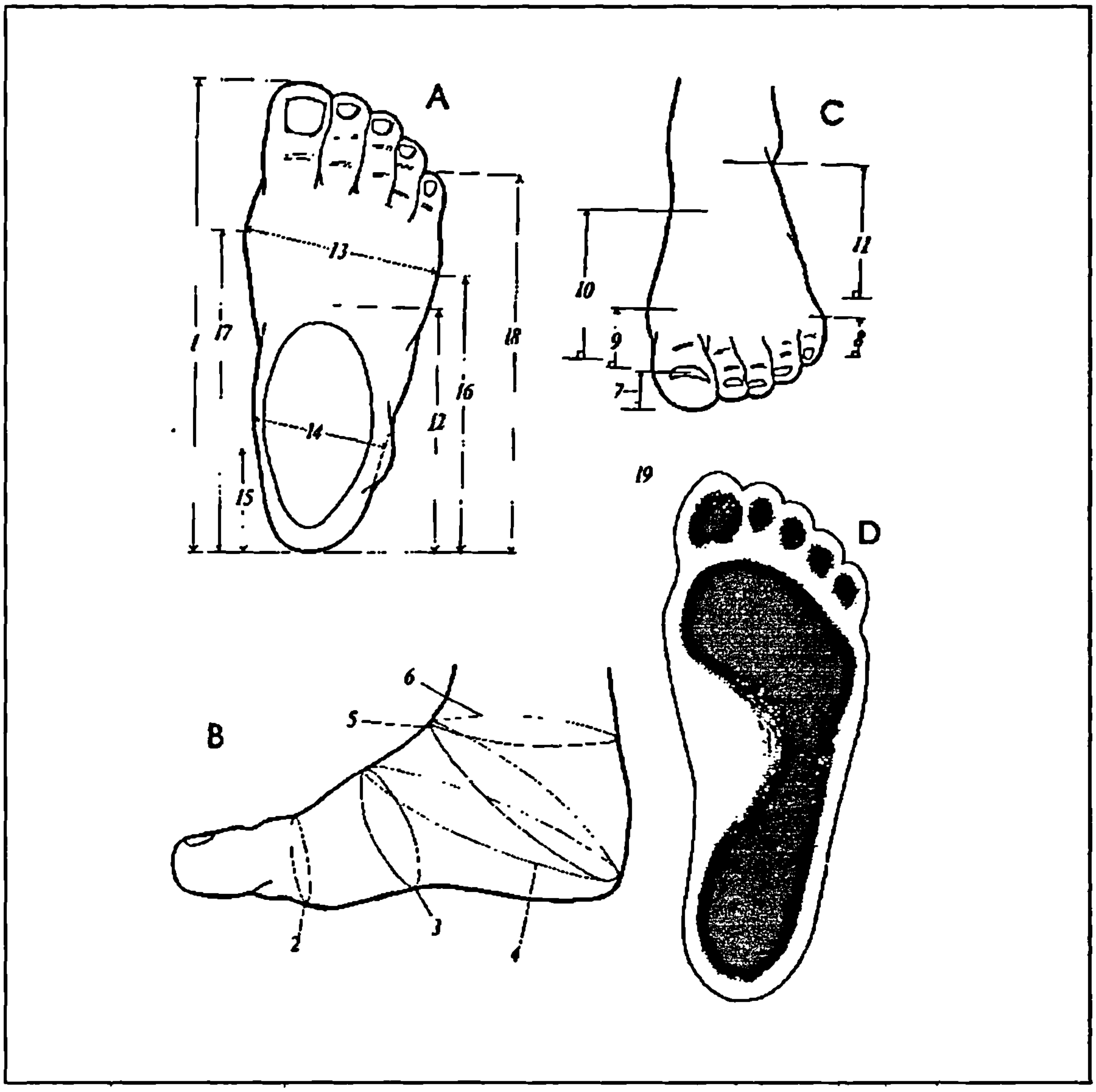

Figure 2.13: CLARKS FOOT MEASURING SYSTEM.

<u>(A) Angle measurements:</u>

The angle measurements are important and useful in determining the last toe shape design in volume shoe trade but they are seldom taken. BS-5943 and Clarks did not adopt these measurements; only the SATRA measuring system mentions these items, the big toe, little toe, joint and seat angles (see **table 2.4(A)**).

(B) Foot length measurements:

It can be seen from **table 2.4(B)** that the BS-5943 system takes only one measurement, the foot (stick) length. However by marking the anatomical features and recording the additional essential information on the measurement chart, most required length measurements can be taken indirectly. It is not necessary[17] to take all the length measurements (as listed in **table 2.4(B)**) for the fitting assessment.

(C) Girth measurements:

In general, all the circumferential measures (as listed in **table 2.4(C)**) are taken in millimetres and the measuring tape should be pulled tight enough to compress the tissues a little, and then released sufficiently to allow the normal elasticity of the tissues to bring the measuring tape back to the correct tension. Also, when taking the horizontal girth, the height position of the foot should be recorded on the measurement chart at the same time. With reference to **British Standard (1980)**, the height of the upper above the base of the heel for boots (normally 140 mm for men) should stated. If the height of the upper exceeds 150 mm, the girth measurements should be taken at 25 mm or 50 mm intervals to the top of the upper.

(D) Height measurements:

The height (as listed in **table 2.4(D)**) should be measured with a metric height gauge (see **figure 2.10**, earlier in this section), and their position correctly marked on the outline diagram of the foot.

(E) Width measurements:

Table 2.4(E) presents the width measurements in existing systems. The function of the width measurements is as important as that of the height measurements. Because of the curvature of the foot, it is not easy to measure and specify the width, many curves blending together on the foot surface in varying proportions. Length and girth measurements alone, without height and width are not enough to determine the correct shape of the foot and designing its shoe last.

[17] Only overall foot length and heel to ball, throat, ankle bone and small toe length are measured.

ANGLE MEASURING ITEMS	BS-5943	Clarks	SATRA
Big toe angle: angle from inside tangent[17] to big toe			*
Little toe angle: angle from outside tangent to little toe			*
Joint angle: angle between tread-line & inside tangent			*
Seat angle: angle from inside tangent to seat width line			*

Table 2.4(A): ANGLE MEASUREMENTS IN THE EXISTING SYSTEMS.

LENGTH MEASURING ITEMS	BS-5943	Clarks	SATRA
Foot length: measured from heel to the longest toe	*	*(1)	*
Heel to medial joint: from heel to medial joint			*
Heel to lateral joint: from heel to lateral joint			*
Heel to medial ball: from heel to medial ball[18]		*(17)	*
Heel to lateral ball: from heel to lateral ball		*(16)	*
Heel to instep: heel to 1st metatarsal-cuneiform joint[19]			*
Heel to throat: heel to talo-navicular joint[20]		*(12)	*
Heel to medial malleolus: heel to medial ankle bone		·	*
Heel to lateral malleolus: heel to lateral ankle bone		*(15)	*
Heel to small toe: heel to the tip of smallest toe		*(18)	*
Heel to 5th metatarsal base: heel to 5th metatarsal base			*
Heel to seat: between heel and seat (heel) width point			*
Big toe length: from inside joint to the tip of big toe			*
Little toe length: from outside joint to little toe tip			*

Table 2.4(B): LENGTH MEASUREMENTS IN THE EXISTING SYSTEMS.
(the marked numbers indicate the measuring items in figure 2.13)

[17] The inside/outside tangent line is defined as a line which tangent to the medial/lateral side of the foot.

[18] Ball: The maximum protuberance of the metatarsal-head of flesh round the joint.

[19] The 1st metatarsal-cuneiform joint is also called the instep point or long heel point, referring to the long heel girth.

[20] The talo-navicular joint is also called the throat or short heel point, referring to the short heel girth.

GIRTH MEASURING ITEMS	BS-5943	Clarks	SATRA
Joint girth: passes over 1st & 5th metatarsal phalangeal joint	*	*(2)	*
Waist girth: smallest circumference slightly behind the joint	*		*
Instep girth: passes over the 1st metatarsal-cuneiform joint	*	*(3)	*
Long heel girth: from instep point around back heel point	*	*(4)	*
Short heel girth: from throat point around back heel point	*	*(5)	*
Malleoli girth: horizontal girth of medial malleolus	*	*(6)	*
Minimum ankle girth: smallest girth just above malleolus	*		*
Calf girth: biggest under knee girth (about 75% knee height)	*		*
Thigh girth: biggest above knee girth	*		
Top girth: girth at the top of the upper	*		

Table 2.4(C): GIRTH MEASUREMENTS IN EXISTING SYSTEMS.
(the marked numbers indicate the measuring items in figure 2.13)

HEIGHT MEASURING ITEMS	BS-5943	Clarks	SATRA
Big toe height: height of the big (1st) toe-tip		*(7)	*
Little toe height: height of the little (5th) toe-tip			*
Highest toe height: the maximum height of 3 other little toes			*
1st metatarsal height: height at the 1st metatarsal-head		*(9)	*
5th metatarsal height: height at the 5th metatarsal-head		*(8)	*
Instep height: height at the 1st metatarsal-cuneiform joint	*	*(10)	*
Short heel height: height at the talo-navicular joint		*(11)	*
Medial malleolus height: height at the medial ankle bone	*		*
Lateral malleolus height: height at the lateral ankle bone	*		*
Under (lateral) ankle height: minimum lateral malleolus height			*
Under knee height: height behind the knee when flexed	*		*
Extra height: upper higher than 150mm (every 25-50mm)	*		*

Table 2.4(D): HEIGHT MEASUREMENTS IN EXISTING SYSTEMS.
(the marked numbers indicate the measuring items in figure 2.13)

WIDTH MEASURING ITEMS	BS-5943	Clarks	SATRA
Joint width: between medial & lateral joint positions		*(13)	*
Seat width: width between in/outside tangent lines		*(14)	*
Instep to inside width: width from instep to inside tangent			*

Table 2.4(E): WIDTH MEASUREMENTS IN EXISTING SYSTEMS.
(the marked numbers indicate the measuring items in figure 2.13)

2.5 Sizing systems

2.5.1 Introduction

Shoe size consists primarily of two measurements, the **overall foot length and ball width** (or **girth**). It seems so simple that by taking these two measurements from the foot and finding the shoe marked with the same length and width you then get a correct fit. Of course, it just does not happen so easily. Shoe sizes are one of the most complicated and erratic areas of the whole shoe fitting process. In respective of the experience of the shoe-fitter, shoe sizes are one of the least understood (or the most mis-understood) elements in shoe fitting. There is an old legend, believed to this day, that our shoe sizes originated back in 1324. King Edward II (1307-1327) decreed that **3 barley corns** taken from the centre of the ear, placed end to end would be the official measurement for **one inch** and each barley corn (about one-third inch) would represent one full shoe size. **(Quimby, 1946)**

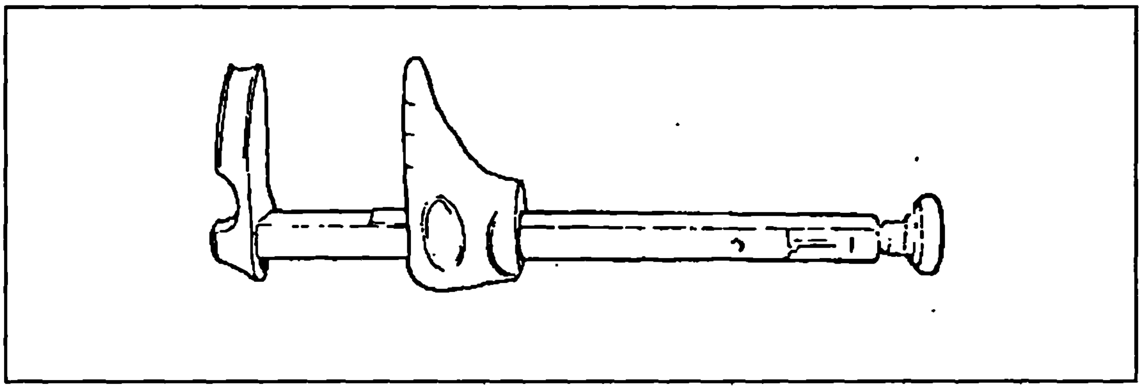

Figure 2.14: A SEVENTEENTH-CENTURY SIZE STICK. (SOURCE: SALAMAN, 1986)

The first recorded description of a shoe sizing system was introduced by Randle Holme in 1688, British genealogist, who referred to a guild of shoes and boots makers who shared a common shoe size scale (**Salaman, 1986**). He then designed a measuring device named "**size stick**", as illustrated in **figure 2.14**, from the form of a caliper gauge with a new sizing system[21]. It is a flat strip of hardwood, graduated in shoe sizes, with

[21] This system used a one-quarter inch scale rather than the one-third inch barleycorn idea of King Edward II. Thus each size progressed by one-quarter inch increments. This system existed in England only. (source: Holme, 1688)

a stop at one end against which the heel rests, and an adjustable stop at the other end which is moved along the stick until it touches the toe. The next recorded description of a shoe sizing system appeared in 1856, in The Illustrated Hand-book of The Foot, by Robert Gardiner of London (**Salaman, 1986**). With for the first time, general agreement among last and shoe makers, the one-third inch size scale was used. Again, it applied only to England. Finally, in 1880 (**Rossi & Tennant,1984**), the world's first full-fledged shoe sizing system was introduced by an American, Edwin B. Simpson of New York. This system detailed the proportional measurements including length, ball width, waist, instep, and heel for lasts and hence shoe sizes. Further, he set up individual systems for infants', children's, women's and men's lasts/shoes. These systems used the one-third inch measurement for each full size. The half-size systems which prevail today were introduced in later 1880.

2.5.2 Sizing classification of shoes

There are three important shoe sizing systems in wide-spread use. They are **American system**, **UK system**, and **Continental system**. All of them are classified both by age and sex groups but overlaps between any two of the various classifications are inevitable (the men's and women's classifications being obvious). In addition, the existing sizing ranges among the adolescent (or juvenile) categories are somewhat limited, in comparison with the much bigger feet of today's adolescents. Nowadays for example many teenagers wear shoes from the adult sizing ranges. The sizing classifications are listed in **table 2.5**.

SIZE GROUPS	AMERICAN	UK	CONTINENTAL
INFANTS'	sizes 0-9	sizes 2-8	sizes 18-25
CHILDREN'S	sizes 8-12	sizes 9-1	sizes 26-30
LITTLE GENTS'	sizes 8-13	-	-
MISSES'	sizes 11-3	-	-
MAIDS'	sizes 2-10	sizes 2-5	sizes 31-39
YOUTHS'	sizes 1-7	sizes 2-5	sizes 31-39
WOMEN'S	sizes 2-12	sizes 2-8	sizes 34-42
MEN'S	sizes 4-16	sizes 6-12	sizes 39-46

Table 2.5: THREE TYPICAL SHOE SIZING CLASSIFICATIONS.
(SOURCE: LARCOMBE, 1990; ROSSI, 1984)

2.5.3 UK sizing and fitting structures

Sizing structures: The UK sizing scale (**Larcombe, 1990**) starts at size 0, representing a length of 4 inches and increases to size 13 (8 $^1/_3$ inches), each interim increase in size being equivalent to $^1/_3$ inch in length. The scale then starts again at size 1, which represents 8 $^2/_3$ inches and proceeds at intervals of $^1/_3$ inch as before. The Continental (Paris) system commences at 0 cm and increases at intervals of $^2/_3$ cm per size. (see *Appendix II-VI* for the detailed comparison of the main sizing systems)

Fitting structures: The fittings of shoe are offered by some manufacturers in a range represented by the letters **A** to **I**. In the UK **A** is the narrowest fitting of the range. Normally there is $^1/_4$ inch between two neighbouring fittings in the same size, eg. 5A & 5B, 5B & 5C, 5C & 5D. The **D fitting** usually represents the average women's fitting, and **E** (5)[22] represents the men's. For children's, **F** (some manufacturers use E) is very popular.

Joint girth grading: For joint girth grading, SATRA Footwear Technology Centre suggests $^3/_{16}$ inch (5 mm) in joint girth between consecutive sizes up to children's size 10 and $^1/_4$ inch (6.35 mm) above size 10.

Reference for original lasts: In the UK, SATRA Footwear Technology Centre recommends a joint girth of 246.5 mm for an average-middle fitting men's last (the average foot girth corresponding to this size/fitting is 250 mm), and a joint girth of 214.5 mm for an average-middle fitting women's last (the average foot girth corresponding to this size/fitting is 226 mm).

Relationship between sizes and fittings: Hardy, Fitting Services Manager of C&J Clarks International Ltd., pointed out that the relationship between sizes and fittings are as follows:

- **1/3" (8.47mm)** between whole sizes.
- **1/6" (4.23mm)** between half sizes.

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[22] In the UK, the numbers are sometimes used for the men's shoes, eg. **5** is used instead of **E**.

- **1/4" (6.35mm)** in girth around the joints between fittings of the same size (eg. 5C and 5D).
- Each of the shoes 1F; 2E; 3D; 4C has exactly the same joint girth measurement.
- When the length increases by a half size and the width fitting remains the same, the increase in the girth is **1/8"** (half a fitting around **3.17mm**).
- Growing room (Clarks' recommendation). **(table 2.6)**

Movement allowance	**1/6" (4mm)**
Growth allowance	**1/6" (4mm)**
Styling allowance	**1/4" (6mm)**
Total allowance	**1/2"+ (14mm)**

Table 2.6: RECOMMENDED GROWING ROOM. (FROM HARDY, ; WITH THE PERMISSION OF THE AUTHOR)

The growth allowance is the space applied at the forepart region for the growth of the child.

Evaluation of these options is required to establish both technical and economic feasibility for the various systems currently being explored with a via to automated selection of appropriate lasts for individual feet. The proposed research will contribute to tighter control of last design and making and has the potential for extensive use.

2.6 Orthopaedic footwear style cutting rules

The style of the upper most commonly used in orthopaedic shoes is the **Derby** (or **Gibson**). Before cutting the patterns, a number of basic reference points and lines are needed and the Derby style is always the basic guide.

2.6.1 Style cutting rules in the UK

The UK orthopaedic footwear industry consists of 30-40 companies ranging from medium to very small. The larger companies are not restricted to footwear and generally supply other orthoses as a major part of their work. The smallest companies are virtually one man and may serve only the private market. Some larger companies are dominated by family firms. These larger firms mainly supply the **National Health Service (NHS)**. There are no special orthopaedic footwear manufacture and last making training course in UK. The pattern cutters may have received formal technical training on a course for the volume trade **(Lord, 1992a)**.

The orthopaedic shoe style cutting rules in UK are no different to those in the volume trade. A Style Development project is under **EUREKA** project has just commenced. The overall aim of the project is to develop standards for styling appropriate to the arthritic foot with particular reference to the implementation of a CAD system for custom orthopaedic footwear **(Lord & Price, 1992)**.

2.6.2 Style cutting rules in the Netherlands

There are about 500 people working in around 130 orthopaedic footwear companies in the Netherlands **(Van der Zande, 1992a)**. According to the reports from TNO Centrum Leder en Schoenen (TNO Centre for Leather and Shoe Research), there are two major style cutting methods being used by most of those 130 manufacturers for the design and making of orthopaedic footwear patterns. The Hanssen Orthopedische Schoentechniek B.V. and Centrum voor Orthopedietechniek Amsterdam (RCA) are the two typical examples of Dutch Orthopaedic systems.

Hanssen Orthopedische Schoentechniek rules:

The basic rules of style design were determined as shown in **figure 2.15** to **figure 2.20**. These rules shape the vamp-point and topline and take the measurement of total-length of the last for the style, allowing fit to be achieved before the patterns are made.

(1) Line *AB* is drawn from the mid-toe point *A* to the mid-heel point *B* to define total-length (**figure 2.15**):

- mid-toe point *A* is at featherline.
- mid-heel point *B* is **1/3** way up from last featherline to the topline backseam tack point *K* (**figure 2.16**), about **22%** of stick length (fixed height).
- the line passes around the lateral border of the last.

(2) Line *DE* is drawn across the joint region so that line *DE* intersects line *AB* at point *C* (**figure 2.17**), (**1/3** of the total-length of the forefoot). The mid-line *AG* of the forefoot is located (**figure 2.18**) where it bisects the metatarsal-line *DE*, to give the vamp-point *G*.

(3) The mid-line *AG* is continued up and the topline marked at point *H* in the proportion:

- $AG_{\text{(mid-toe to vamp-point)}} : GH_{\text{(vamp-point to topline)}} = 2/3 : 1/3$

(4) Each side of the metatarsal-line *DE* is again bisected at point *I* on line *GE* and point *J* on line *DG* and a lateral line *IK* and medial line *JK* are drawn back from these quarter points *I*, *J* to the topline backseam tack point *K* of the heel (see **figure 2.19** and **figure 2.20**).

(5) A line is drawn around the girth through the topline point *H* on the front cone to meet the lines *IK* and *JK*.

(6) Following step (4) & (5) the topline is determined by drawing a freehand line from the point *K* at the mid-heel, using the medial line *IK* as a guide but blending up to the topline point *H* and dropping **5mm** below the lateral line *JK* under the malleoli, then again blending upwards to the topline point *H*.

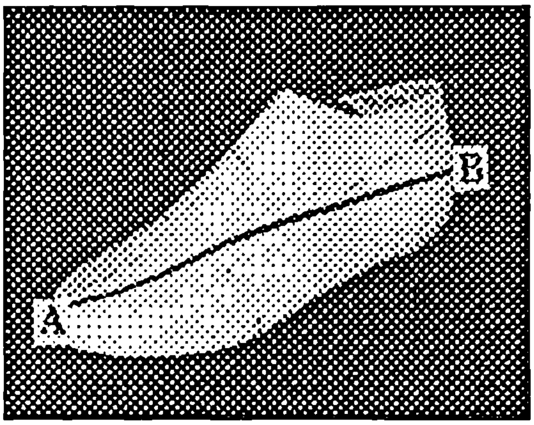

Figure 2.15:
THE TOTAL-LENGTH *AB*.

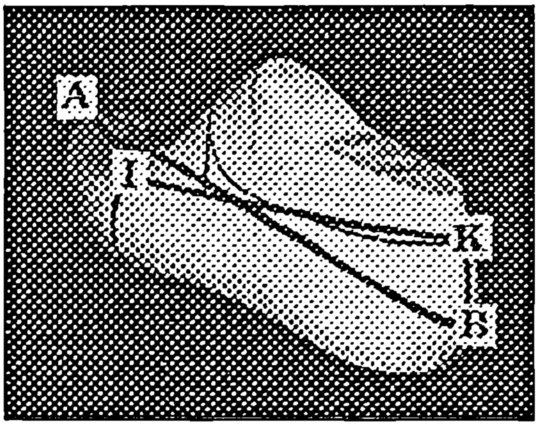

Figure 2.16:
BACKSEAM-TACK POINT *K*.

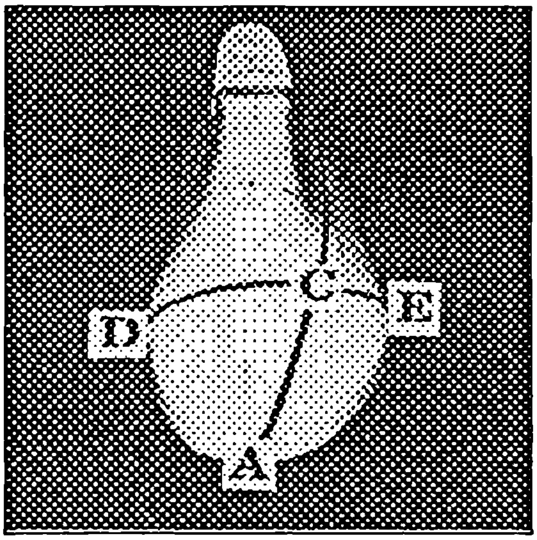

Figure 2.17:JOINT-LINE *DE* INTERSECTS LINE *AB* AT *C*.

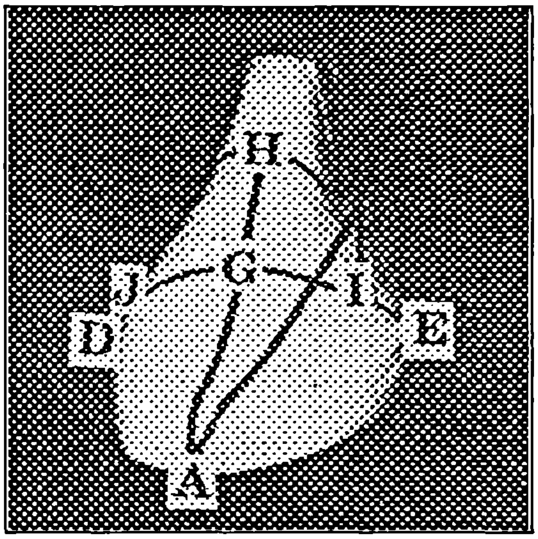

Figure 2.18: VAMP-POINT *G* & FOREPART TOPLINE POINT *H*.

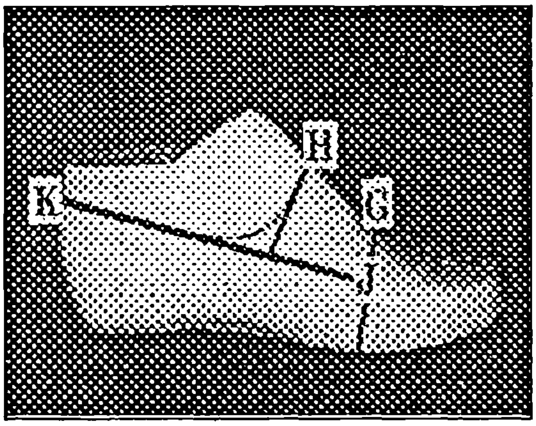

Figure 2.19:
MEDIAL POINTS & LINES.

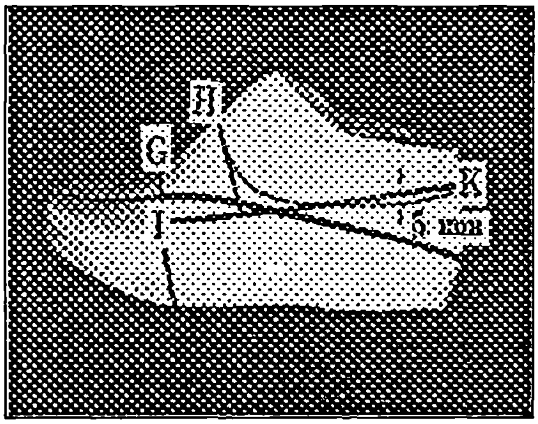

Figure 2.20:
LATERAL POINTS & LINES.

Centrum voor Orthopedietechniek Amsterdam (RCA) rules:

During the visit to TNO and Centrum voor Orthopedietechniek Amsterdam (RCA), on Wednesday, Thursday 13-14th May, 1992, basic rules for orthopaedic footwear style design were demonstrated. During the demonstration, the RCA used two different vacuum forming materials for making shell shoes. The first one was a transparent shell made from rigid PVC material (the same as Hanssen's bottom material) for checking last shape only. The other shell was made from 3-5mm soft EVA sheet for walking trials. These rules are different from Hanssen's. Most of the design work used **2-D** patterns, but measurements were taken from **3-D** last (see below).

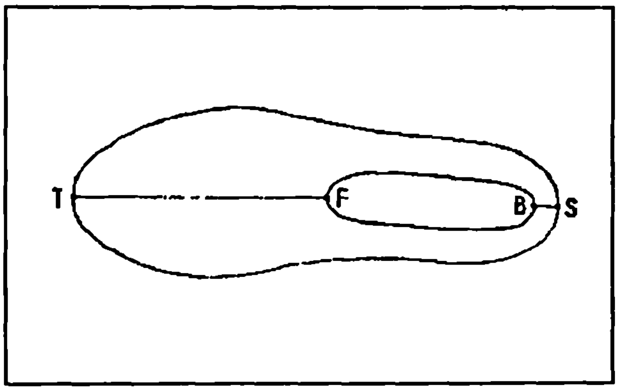

Figure 2.21: FOREPART & BACKPART CENTRE-LINE (*TF&BS*)

<u>Measures taken on 3-D last</u>:

(1) A line is drawn from the mid-toe point *T* to the back-heel seat point *S* by passing around the upper cone area to define the forepart and the backpart centre-line *TF* & *BS*: **(figure 2.21)**

- mid-toe point *T* and the back-heel seat point *S* are both at the featherline.
- the line passes around the central top of the forepart cone and backpart cone of the last.

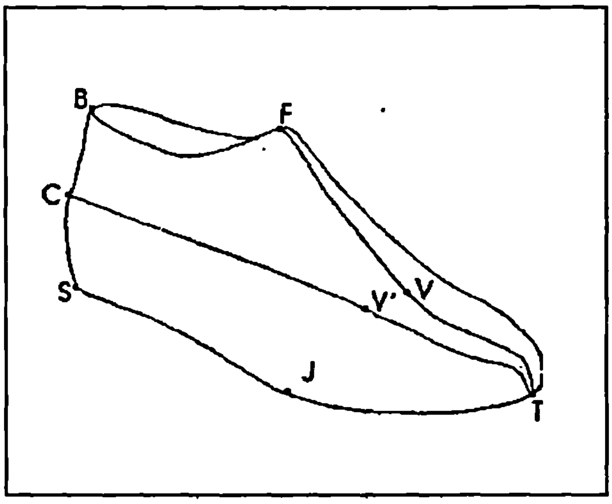

Figure 2.22: DEFINE TOTAL-LENGTH *TC* AND ALL MEASURING REFERENCE POINTS.

(2) A line is drawn from the mid-toe point *T* to the back-heel curve point *C* to define total-length *TC*: **(figure 2.22)**

- back-heel curve point *C* is at the farthest point of the back-heel curve of backpart centre-line *BS*.
- the line passes around the lateral border of the last.

(3) The length of *TV'* which is **1/3** (forepart) of the total-length *TC* is measured. The point *V'* is transferred onto the forepart centre-line with the same measures to give the vamp-point *V*; then

- $TV = TV' = 1/3\ TC$

(4) A point is marked at the backpart centre-line to define back-heel height (or topline backseam tack) point *H*:

- back-heel height *HS* is about **65mm** (fixed height: about 22% of stick length) for the UK men's size 8 and **55mm** for the UK women's size 5.

(5) Three lengths (*VH, VC, VS*) are measured from the vamp-point *V* to the back-heel height point *H*, back-heel curve point *C*, and back-heel seat point *S*. Then a joint-point *J* is marked onto the featherline at the lateral joint area.

Patterns design on 2-D mean-form[23]:

(6) A meam-form pattern (**figure 2.23**) is created from its last by using brown paper on which are marked all the reference points (ie. *V, H, C, S, T,* and *J*).

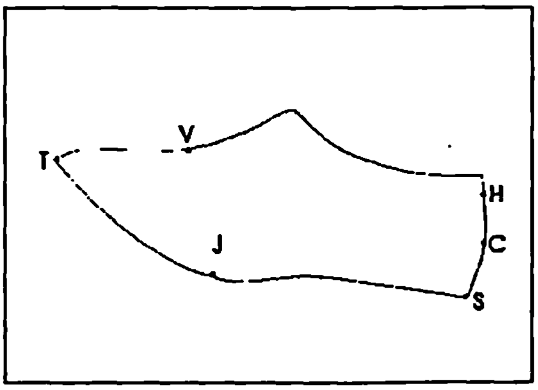

Figure 2.23:
MEAN-FORM PATTERN WITH REFERENCE POINTS MARKED.

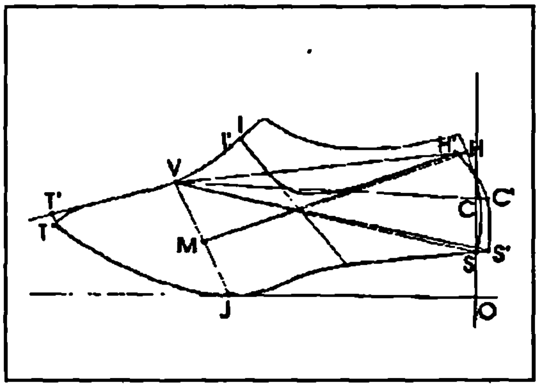

Figure 2.24:
DUPLICATED MEANFORM PATTERN WITH MARKED REFERENCE.

(7) This mean-form pattern is duplicated onto cardboard with reference points marked: (**figure 2.24**)

[23] Mean-form pattern is a flattened standard pattern which is taken from an average last upper surface area (between inside and outside formes).

- one horizontal line *OJ* and one vertical line *OS* are drawn, intersecting at the base-point *O*. Then the measures of the heel pitch height upwards from base-point *O* are taken and a point *S* is marked on the vertical line *OS*.
- the back-heel seat point is adjusted onto the *S* position of the vertical line *OS*. Then the mean-form pattern is turned to the proper position where joint-point *J* of the featherline touches the horizontal line *OJ*.
- the mean-form pattern is duplicated and referenced onto cardboard.

(8) A line is drawn from vamp-point *V* to a new mid-toe point *T'* at a tangent to the mid-toe-vamp line *VT* to define front centre-fold line *VT'*.

- front centre-fold line *VT'* intersects the smooth extension line of featherline *TJS* at point *T'*.

(9) A line *VJ* is drawn from vamp-point *V* to point *J* and a point *M* is marked halfway along this line *VJ*.

- $VM = MJ = 1/2\ VJ$

(10) The back-curve line *HCS* should be modified as *H'C'S'* to avoid top-line gap and provide a pocket for the stiffener (or counter).

- $VH' = VH$ - 5mm.
- $VC' = VC$ + 2mm.
- $VS' = VS$ + 5mm.
- a new back-curve line is drawn from *H'* through *C'* to *S'*.

(11) A line *MH'* is drawn from point *M* to new back-heel height point *H'* for top-line sketching reference. The forepart top-line point *I*[24] (or *I'*) is found by measuring back-heel height length, and marked. A line at 90 degree to the forepart centre-line is drawn from the top-line point *I* (or *I'*) to meet the featherline, and a freehand topline *IH'* (or *I'H'*) is then sketched.

[24] *I*= 65mm for UK men's size 8; *I'*= 55mm for UK women's size 5.

2.7 CAD/CAM systems for footwear

2.7.1 Introduction

Competition is the name of the game among the CAD/CAM companies in recent years, since the footwear industry has no excuse but to face the explosion in the development and use of CAD/CAM systems. The question is: The CAD/CAM systems really able to play a major role in automating footwear production in the future? A footwear CAD system is mainly used to construct, modify and grade the shoe patterns, and then provide the digitised data for the continuous cutting jobs. Some systems also have the capability of designing or styling shoes, including uppers, insole, and outsoles (or units), even the decorative components. After the details of a design and its patterns are stored in CAD memory, this information can be used to drive a cutter to cut out these patterns (components) or to generate packaged stitching programmes for automatic stitching machines.

The first true CAD system designed specifically for footwear was by the **Camsco Apex Ltd.** and was launched in 1978. It evolved from systems originally developed for the aircraft industry (**Perkins & Hackney, 1986**). Then, a number of footwear companies were developing CAD systems. Over the past few years, while computer prices have plummeted, developments have accelerated. At the 1991 ISM Show (International Shoe Machinery Show, Pirmasens, Germany), more than ten companies were demonstrating CAD/CAM systems specifically designed for shoes. However, only six of them were offering their systems commercially and showing both 2D and 3D CAD/CAM. These six companies are Atom+Vicam, Clarks, Gerber, Lectra, Microdynamics, and United Shoe Machinery (see *Appendix II-VII* for the details of their systems layout).

2.7.2 CAD/CAM Systems for orthopaedic footwear

There is no doubt that computer aided technology has been applied in many manufacturing areas with its advantages of speed and improved quality; also the graphic utilities are now common for aesthetic product design. In volume shoe trade, the CAD/CAM has proved itself valuable, particularly in the sphere of new style design, development and pattern engineering. The shoe designer creates new styles on the computer screen and makes the patterns at the same time. Then these pattern pieces can be modified, decorated, nested and graded for required sizes automatically and then link directly with a CAM (eg. cutter), which will produce these upper pieces.

In orthopaedic footwear manufacture, the advanced technology is very much less evident than in the volume shoe trade. The orthopaedic footwear industry makes bespoke shoes for individuals who are unable to wear normal shoes because of a medical condition. In the United Kingdom, orthopaedic shoe making is a craft process. It takes a very long time to complete the shoes and the arrangement of clinic visits. The NHS contracts with UK orthopaedic footwear manufacturers allow **6 weeks** from foot measurements to production of shoes for trial fit. Allowing for arrangement of clinic visits, it is common for the orthopaedic shoes to be delivered between **2** and **3 months** after the initial foot measurement. So application of computer-based technology is an obvious consideration to help solve some of the perceived needs in orthopaedic shoes provision.

Clarks' specialist CAD/CAM system, Shoemaster, which enables their designers to style shoes on screen in 3D and flatten this style into 2D patterns. Then provides a linking computer-controlled CAM (eg. cutter and stitching machines) for making their upper parts, is already in use by the fashion shoe trade. The system is now being developed by the EUREKA-SELECT team, who will add the ability to apply a shoe style design to non-standard orthopaedic shoe lasts. Using measurements of the patient's foot, the system will select the best fit from a small library of digitised lasts representing a range of abnormal foot shapes. Scaling and custom modification of the computer model will allow an individual last to be developed and stored for each patient. Patients will then be able to choose up-to-the-minute designs from a parallel library of shoe styles, which will be married by the computer with their individual last to guarantee a perfect fit every time new shoes are ordered. **Figure 2.25** illustrates that the upper patterns can be transferred onto different types of lasts. This also indicates that the Hi-Tech (CAD/CAM) enable to bring fashionable style to orthopaedic footwear.

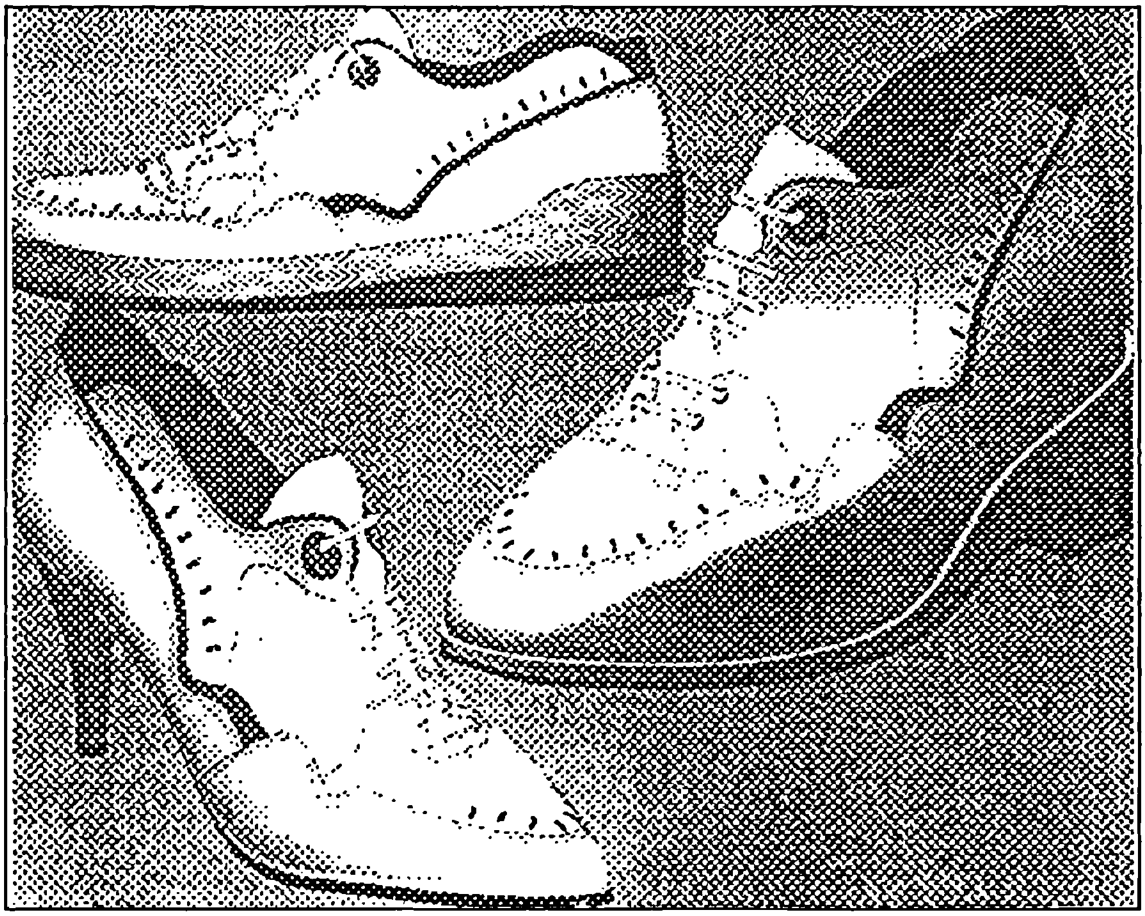

Figure 2.25: CAD/CAM BRING FASHION TO ORTHOPAEDIC FOOTWEAR. (FROM CLARKS' POSTER, WITH PERMISSION OF SECTION MANAGER)

CHAPTER 3
RELATIONSHIP BETWEEN FOOT AND SHOE LAST SHAPE

3.1 Introduction

In this chapter, a series of inter-related experiments will be carried out to find the relationship between the shape of the foot and the last. The overview of the experimental processes is documented by reference to the relevant equipment, operation plans, and the original results obtained. First a method is introduced for the model last R&D, which can be used as a general procedure for last assessment. An example foot (plaster cast model) with its made to measure last and the original stock model last are selected to illustrate this method. This study is in collaboration with De Montfort University[1] (Leicester Polytechnic), School of Design and Manufacturing. The British United Shoe Machinery (BUSM) Ltd.[2] and C&J Clarks International Ltd.[3] provided their latest developed 3-D digitisers to take cross-sections of the foot and lasts accurately and automatically.

This study will support and identify the difference firstly between the foot and its made to measure last which is in accordance with the shape of a model last selected from stock, and secondly between the stock and the made to measure last. By comparing the volumetric data, surface areas, and the cross-sectional data derived from the lasts and foot, an effective allowance value can be provided to produce an accurate standard model last. Using these evaluations, criteria for designing and manufacturing standard model lasts can be developed. This may also help the footwear industry, who aim to make comfortable, well-fitting shoes.

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[1] MA Fashion and Textile Studies: School of Design and Manufacture, De Montfort University, P.O. Box 143, Leicester LE1 9BH.

[2] BUSM CRISPIN (3-D) SYSTEM: British United Shoe Machinery Ltd., P.O. Box 88, Ross Walk, Belgrave, Leicester, LE4 5BX.

[3] CLARKS SHOEMASTER SYSTEM: C&J Clarks International Ltd., 40 High Street, Street, Somerset, England BA16 0YA.

3.2 Aims and objectives

The aims of the study are in the first place to investigate the differences between the shoe last shape and the foot of a normal subject in order to improve the fit and overall comfort of manufactured footwear, and then to evaluate the possibilities of applying this model to patients who require orthopaedic footwear prescription. The specific objectives of this study are:

- To review the relevant literature concerning last design and manufacture.
- To identify the correlation between foot measurement and present last design and manufacturing methods.
- To identify suitable research methods which with further the understanding of the relationship between the last and foot, in terms of both surface and volumetric measurement change.
- To identify modifications that can be made to the standard model last in response to fashion styling requirements and their effect on the fit and comfort of footwear.
- To evaluate the possibility of applying this study to the special orthopaedic requirements.
- To draw conclusions and make some recommendations for the future development of last design and manufacture with a view to upgrading the quality of footwear products.

3.3 Trial protocol

The stages in this trial can be identified as:

- Subject selection and foot measurement.
- Selection and modification of stock last.
- Plaster foot model making.
- Digitising:
  (1) Last digitising.
  (2) Plaster foot model digitising.
- Cross-section taking.
- Recording and analysis of results.

3.3.1 Subject selection and foot measurement

In the orthopaedic shoe trade in the UK, bespoke shoes are either made to measure or from a plaster cast foot model; In UK volume shoe trade, women's size 5 model last (D fitting) is usually used for an average middle fitting standard. Accordingly, a female volunteer (5D12) of nominal size 5D was selected from among BA students of Fashion & Footwear Design at De Montfort University (formerly Leicester Polytechnic). The foot was measured, using methods similar to those used in volume shoe manufacturers and orthopaedic trade, including length, girth, height, width measurement and an outline diagram was produced (see *Appendix IV-II* for details of the foot measuring items).

3.3.2 Selection and modification of stock last

The model last (H6028) was selected from Clarks' current range, of similar design to those used in orthopaedics, ie. for low-heeled (lower than 1 $^1/_2$ inches) shoes fastened over the instep. Both the shoes and their lasts are available from stock. The modified model last (H6028S) was made by **Mr. T. Hannay**, senior orthopaedic model last maker of H.W. Poole & Sons Ltd., Leeds. To make the model last, a foot draft (outline diagram or blue-print) and all the foot measures (with special information marked) are required. The specified procedure is as follows:

- Prepare and check the draft, the measurements and all information taken from the subject.
- Select a pair of stock last (from Poole's last storage house) to match the required measures eg. stick length, heel to ball length, forepart width, joint girth and heel pitch height.

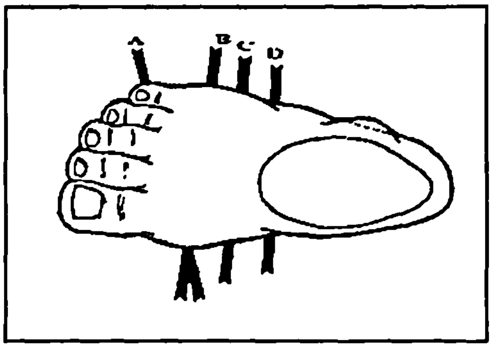

Figure 3.1:REFERENCE FOR LAST ALLOWANCES

- Confirm shoe (or last) size as follow:

last length = foot length + $1\,{}^{1}/_{2}$ shoe sizes (about ${}^{1}/_{2}$ inch)

- Mark all reference positions on the last against the draft.
- Check all allowances required by insole thickness (see **table 3.1 & figure 3.1**).
- Re-shape and modify the last by sanding off or adding leather, cork or hard-foam plastic patches (checking the reference positions and measures at all time, especially the measures of heel to ball length and joint girth).

INSOLE	ALLOWANCES REQUIRED			
	A	B	C	D
NONE	12 mm	6 mm	3 mm	3 mm
3 mm	25 mm	18 mm	12 mm	12 mm
4 mm	28 mm	25 mm	15 mm	15 mm
6 mm	31 mm	28 mm	18 mm	18 mm

Table 3.1: LAST ALLOWANCES REQUIRED vs. INSOLE THICKNESS. (WITH PERMISSION OF H.W. POOLE & SONS LTD.)

3.3.3 Plaster foot model making

It is impossible to cut the feet into slices to study their cross-sectional relationship but plaster casts can be made and reproduced. The complete shape of a foot can be obtained by making a plaster model. In our trial, this was made by the researcher in association with Mr. K. Walker, senior lecturer of Department of Ceramics Studies at

De Montfort University. The method[4] of making a plaster foot model does not need any complicated apparatus, the required materials being listed in **table 3.2.** The plaster foot model making procedures are as follows:

(1) Mix the plaster of paris and water, and then pour into a bevel-sided container. Warm or tepid water could cause the plaster to set more quickly; (2) Press the foot evenly into the layer of plaster; (3) Wet the plaster bandage and lay it on the foot. (4) When plaster is fully set, remove the foot, and re-build the plaster shell with elastic bands; (6) Mix the plaster of paris and water again, then pour into the re-built shell; (7) After the male foot model is fully set, remove the shell.

ITEMS	QUANTITY	REMARK
PLASTER OF PARIS	9 - 10 lb.	1 lb. with 0.5 pt. water
PLASTER BANDAGE	10 m long	about 10 cm wide
VASELINE	1 jar	to prevent adhesion
CLAY or PLASTICINE	9 - 10 lb.	to divide the matrices
BEVEL-SIDED CONTAINER	1	
BOWL	1	
SCISSORS	1	
ELASTIC BANDS	as required	
WATER	10 pt.	

Table 3.2: MATERIALS FOR PLASTER FOOT MODEL MAKING. (FROM K. WALKER OF DE MONTFORT UNIVERSITY)

3.3.4 Last digitising

Both the made to measure last (H6028S) and its based stock model last H6028 were digitised by the Clarks Shoemaster 3-D manual digitiser, used for capturing last surface data (see **figure 3.2**). The last surface including the bottom is marked up with a patch-

[4] This method is a guide to make the plaster model of whole foot, especially above the ankle bone position. The Langer Orthotic Laboratory (UK) Ltd. provides a useful chart to take the neutral subtalar position plaster impressions of the feet.

work (or grid) of lines. The intersections of these lines are digitised into systems, typically between 70 and 200 reference points. Once in the system, a surface model is developed to pass through the grid points, and the last is displayed as a shaded model (see **figure 3.3**). Several views can be created initially, and from the initial drawing, different views can be obtained during or after digitising the model last. Users are able to check rapidly and to select the required view point by dynamic rotation of the wire-framed model (see **figure 3.4**). The model last is mounted horizontally on the base plan with the correct heel pitch height and fixed firmly from the last bottom.

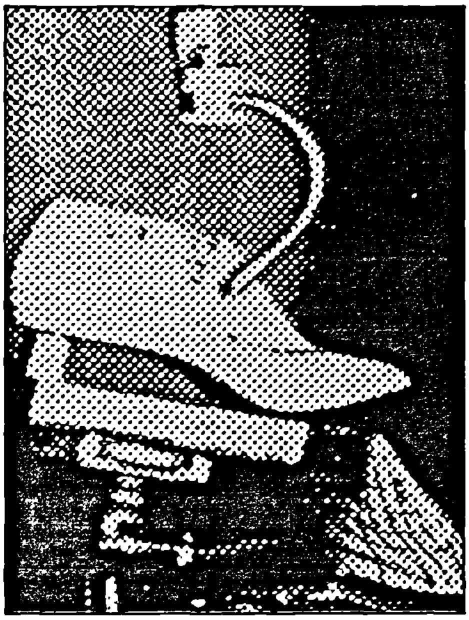

Figure 3.2: SHOEMASTER 3-D MANUAL DIGITISER.

Three reference points (ie. the top & bottom of heel-curve and centre of toe) and the pitch height value should be identified before digitising.

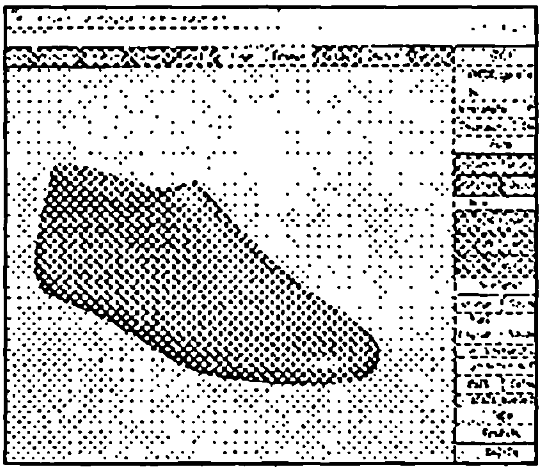

Figure 3.3: THE DIGITISED LAST FROM SHOEMASTER.

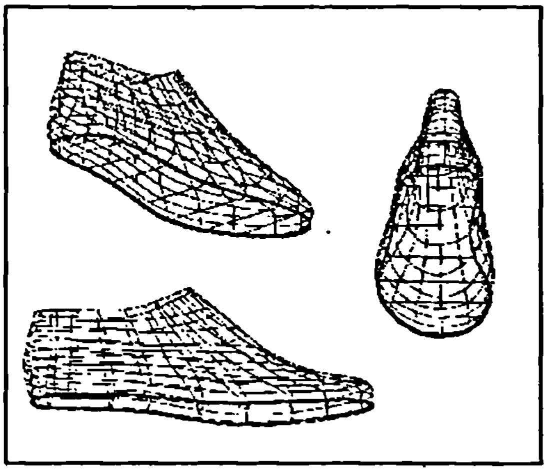

Figure 3.4: LAST DISPLAYED WITH REQUIRED VIEWS.

The digitiser is able to work starting from either the upper or bottom. It also gives warning (or error) messages if the upper and bottom points at the feather-edge[5] area do

[5] Feather (also called feather-line or feather-edge): The boundary line around the upper where it joins the welt or the sole; the corresponding line around an insole or a last.

not meet and offers an auto-rectifying function. After digitising, the Clarks Shoemaster digitiser is able to check the stick length and joint girth measures of the model last and make some styling reference points[6] for further style design tasks. Then the digitised last is saved in the last library of the computer (see *Appendix III-I* for the details of the digitised last data).

3.3.5 Foot model digitising

Unlike the smooth last shape, the plaster cast foot model maintains its irregular surface. It is necessary to digitise the foot shape actually. The auto-rectifying function in the Shoemaster digitiser will make the uneven foot shape smooth. For this reason, the plaster cast foot model was digitised by the BUSM Crispin 3D laser digitiser. This commercial 3D-CAD package is currently being completed (see **figure 3.5**).

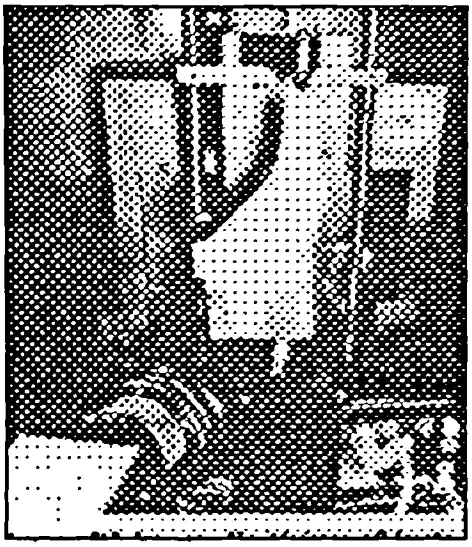

Figure 3.5: BUSM CRISPIN 3-D LASER DIGITISER.

The system uses an optical device, based on tri-angulation. It can produce a sharp spot of light with a laser, and pick it up with displaced cameras. The foot model is coated white and mounted vertically (with toe uppermost) in the machine. The laser beam is directed at the foot model and its reflection is picked up by two digital cameras. The turn-plate, where the foot model is mounted, turns at 5 degree rotations, and moves downward at 5 mm intervals. It takes about 15 minutes to digitise the foot model automatically. Then the digitised last is saved in the last library of the computer (see *Appendix III-II* for the details of the digitised foot data).

[6] These styling reference points are **last girth points** (including inside, outside and centre point), **back-topline height points** (including inside, outside and centre-back point), inside & outside **ankle height points** and the **vamp-point**.

3.3.6 Cross-section taking

The BUSM 3-D Crispin system is able to produce cross-sections from the digitised plaster cast foot model automatically, because of its data structure. From the Clarks Shoemaster digitiser, the raw data does not represent cross-sections but these can be extracted from the surface model which is fitted through the data.

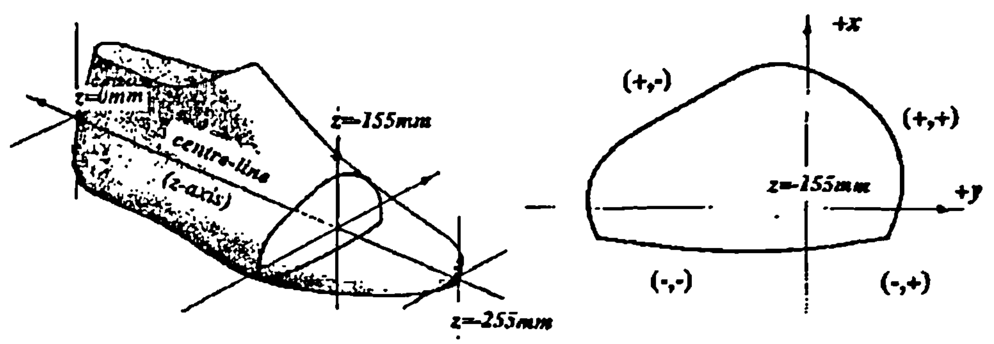

Figure 3.6: LOCATION OF DIGITISED POINT $P(x_0, y_0, z_0)$.

The coordinate is introduced as Cartesian Space Coordinate[7]. The foot (or last) model is mounted vertically with toe uppermost position where the centre line is assigned to match the *z-axis* in the machine (see **figure 3.6**). And the digitiser is assumed at the *x-axis* of the Cartesian Coordinate plane *O-xy*, through the Origin point *O*. A point $P(x_0, y_0, z_0)$ is digitised from the foot (or last) model and a plane drawn through the point *P* perpendicular to the *z-axis* will intersect the *z-axis* at the position of $z = z_0$; similarly at $x = x_0$ and $y = y_0$.

The Crispin digitiser is designed by taking cross-sections on the ***xy-plane***, and adjusted at intervals of 5 mm, which means that *z-axis* is assigned to be a series of fixed numbers (i.e. z = *0, -5, -10,......, -250, -255*). With the value of z being set as a constant, the circumferences and the areas of these cross-sections are easily calculated. The Shoemaster system can also provide the cross-sectional areas which correspond with the

[7] The Cartesian Space Coordinate is also called the right-handed coordinate system, i.e. if the index finger of the right hand points along the positive *x-axis* and the middle finger along the positive *y-axis*, then the thumb will point along the positive *z-axis*.

assigned Crispin coordinate. **Figure 3.7** and **figure 3.8(A)** and **(B)** show cross-sections of foot and lasts respectively, at the 1st (*z= -170 mm*) & 5th (*z= -155 mm*) metatarsal-head position (for more detailed cross-sectional comparison, see *Appendix III-III*). The co-ordinates of these cross-sections are as follows:

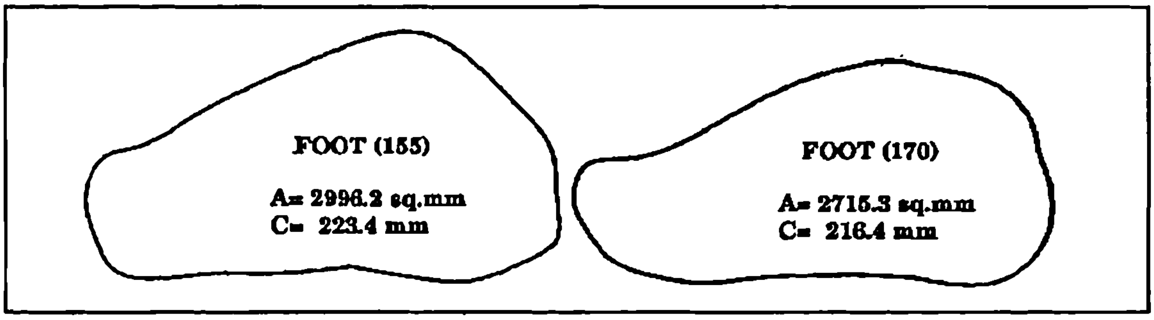

Figure 3.7: EXAMPLES OF TWO FOOT CROSS-SECTIONS.

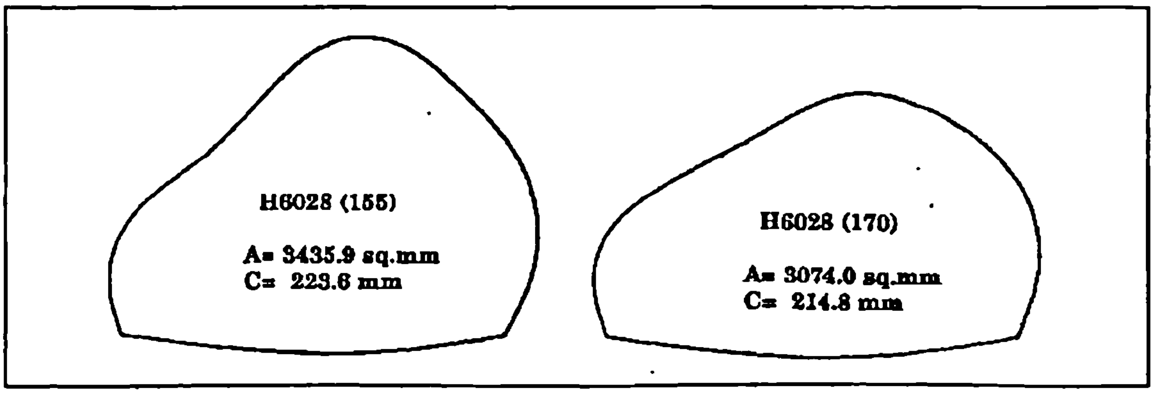

Figure 3.8(A): EXAMPLES OF TWO LAST (H6028) CROSS-SECTIONS.

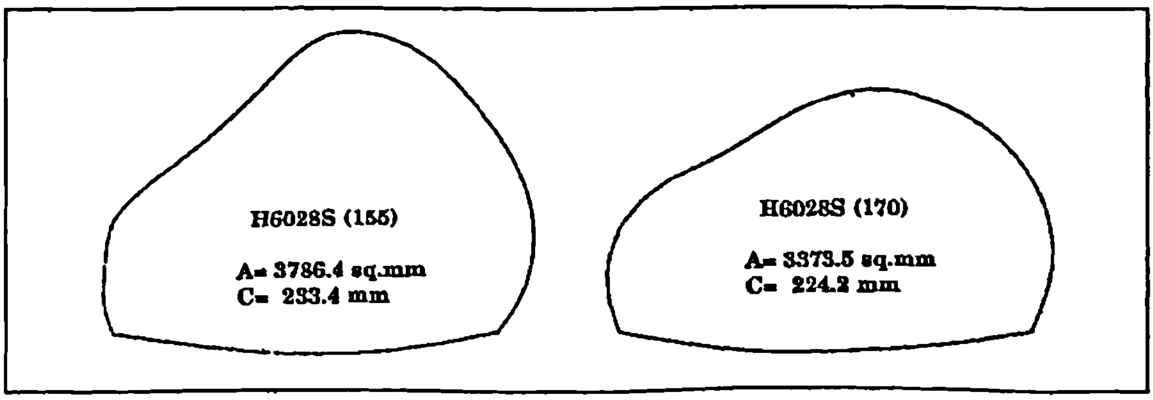

Figure 3.8(B): EXAMPLES OF TWO LAST (H6028S) CROSS-SECTIONS.

3.3.7 Lasts and foot volume measurement

There are two methods of calculating the volume of the foot and lasts. One is **Archimedes' Theorem.** The volume of an irregular solid (eg. the foot and lasts) could be calculated by measuring the water displaced when it is entirely immersed. The other method is by using the theorem of **Parallel Cross-sections.** We begin with a last (or foot), through which we pass a coordinate line *z-axis* to match the centre line of the last (see **figure 3.9**).

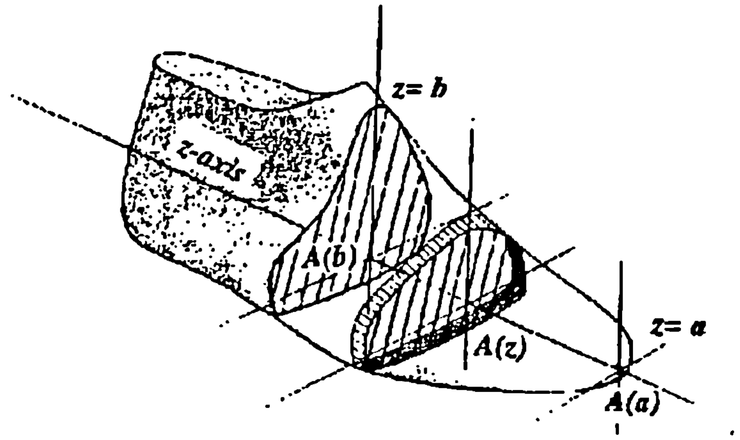

Figure 3.9: LAST LIES BETWEEN $z=a$ & $z=b$.

We take the areas of the last between toe-end $z = a$ (*-255 mm*) and instep $z = b$ (*-140 mm*). The area of these cross-sections $A(z)$ has coordinate z. As the cross-sectional area, $A(z)$, varies continuously with the parameter z, we can find the volume V of the last, by integrating $A(z)$ from $z = a$ to $z = b$:

$$V = \int_a^b A(z)\,dz \qquad a=-255,\ b=-140$$

Let S be the solid of the last (or foot) in question and let the *set* $P = \{z_0, z_1,...,z_n\}$[8] be a partition of S between $[a, b]$[9]. For each sub-interval $[z_{i-1}, z_i]$ let A_{i-1} and A_i respectively be the minimum and maximum areas of A on $[z_{i-1}, z_i]$. Let S_i be that portion

[8] The notation $\{z_0, z_1,...,z_n\}$ will be used to denote the set, $z_0, z_1,...,z_n$ are elements of set.

[9] The closed interval *[a, b]* is the open interval *(a, b)* together with the endpoints *a & b*.

of the last (or foot), which corresponds to the interval $[z_{i-1}, z_i]$ and let V_i be its volume. S_i contains a solid of cross-sectional area A_{i-1} with a thickness $d(z_i)$ and a cross-sectional area A_i with $d(z_i)$. This suggests that

$$A_{i-1} \times d(z_i) \leq V_i \leq A_i \times d(z_i)$$

Summing these inequalities from $i = 1$ to $i = n$, we can then get the total volume V, between minimum volume V_{min} and maximum volume V_{max}.

$$V = \sum_{i=1}^{n} V_i \qquad V_{max} = \sum_{i=1}^{n} A_i \times d(z_i) \qquad V_{min} = \sum_{i=1}^{n} A_{i-1} \times d(z_i)$$

3.3.8 Lasts and foot surface area measurement

Using the same principle as in **Parallel Cross-section**, we begin with a last (or foot) through which we pass a coordinate line *z-axis* to match the centre line of the last (refer to **figure 3.9**). As in the figure, we take the last areas between toe-end $z = a$ (*-255 mm*) and instep $z = b$ (*-140 mm*). The circumferential length of these cross-sections $C(z)$ is coordinated with *z-axis*, and parametrized by a pair of continuously differentiable functions[10].

To calculate the circumferential length, $C(z)$ can be approximated by the union of a finite number of line segments and each point t in closed interval $[c, d]$ gives rise to a point $P = P(x(t), y(t))$ which lies on the circumference $C(z)$. By choosing a finite number of points in closed interval $[c, d]$

$$c = t_0 < t_1 < \ldots < t_{i-1} < t_i < \ldots < t_{n-1} < t_n = d$$

$$C(z): x(t), y(t) \qquad t \in [c, d]$$

a finite number of points of $C(z)$ can be obtained.

[10] The functions have continuous first derivatives.

$$P_0, P_1, \ldots, P_{i-1}, P_i, \ldots, P_{n-1}, P_n$$

When joining these points together consecutively by line segments, the circumference is shaped as a polygonal path (*L*).

$$L = \overline{P_0P_1} \cup \ldots \cup \overline{P_{i-1}P_i} \cup \ldots \cup \overline{P_{n-1}P_n},$$

The length *L* of such a polygonal path is the sum of the distances between consecutive vertices:

$$Length\ of\ L = d(P_0, P_1) + \ldots + d(P_{i-1}, P_i) + \ldots + d(P_{n-1}, P_n)$$

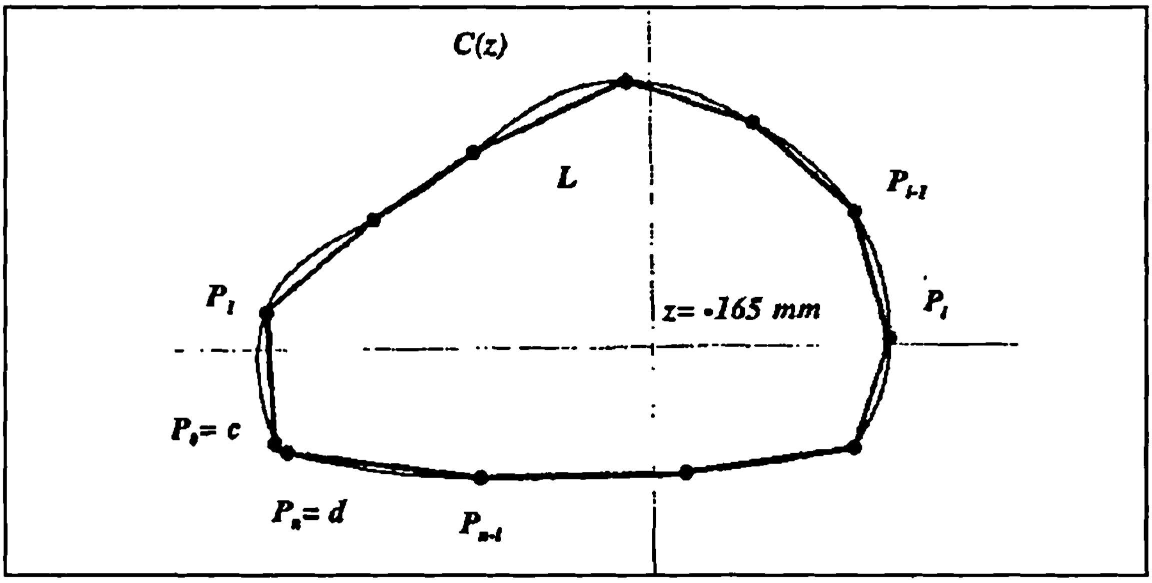

Figure 3.10: A POLYGONAL PATH *L* INSCRIBED IN CIRCUMFERENCE, WHICH SERVES AS AN APPROXIMATION TO THE *C(z)*.

The polygonal *L* serves as an approximation to *C(z)* (see **figure 3.10**), but obviously a better approximation can be obtained by adding more vertices to *L*[11], and then we can approach the length of *L* to the length of *C(z)*, for each *L* inscribed in *C(z)*:

$$Length\ of\ L \leq length\ of\ C(z)$$

[11] The more points added, the greater will be the similarity in length between *L* and *C(z)*.

The length of the circumference can be calculated by integrating $C(z)$ from $t = c$ to $t = d$.

$$C(z): x(t), y(t) \qquad t \in [c, d]$$

$$\text{Length of } C(z) = \int_c^d \sqrt{[x'(t)]^2 + [y'(t)]^2}\, dt$$

If the cross-sectional circumference $C(z)$ varies continuously with the parameter z, we can then find the surface area (SA) of the last by integrating $C(z)$ from $z = a$ to $z = b$:

$$SA = \int_a^b C(z)\, dz \qquad a=-255,\ b=-140$$

the inequalities can also be suggested as follow:

$$C_{i-1} \times d(z_i) \leq SA_i \leq C_i \times d(z_i)$$

Summing these inequalities from $i = 1$ to $i = n$, we can then get the total surface area SA between minimum surface area SA_{min} and maximum surface area SA_{max}.

$$SA = \sum_{i=1}^{n} SA_i \qquad SA_{max} = \sum_{i=1}^{n} C_i \times d(z_i) \qquad SA_{min} = \sum_{i=1}^{n} C_{i-1} \times d(z_i)$$

3.4 Results

3.4.1 Foot and last measurements

Table 3.3 shows completed foot measurement records (taken from a female volunteer subject of nominal size 5D). It lists all the items measured and the measurements for each on right and left foot, with the average in the right hand column. The foot measurements (including length, girth, height, width measurement) were taken using methods similar to those in the volume shoe manufacturers and orthopaedic trade. Then an outline diagram was drawn for designing the made to measure (custom modification) last.

Table 3.4 shows the differences, *d(x)=last.x-foot.x,* between the last and the foot measures. There are only five measurements which can be absolutely coordinated from the foot onto the last surface, ie. stick length, medial heel to ball length, joint girth, joint width, and seat width. The negative data indicate that the measures of the foot (*foot.x*) are bigger than those of the last (*last.x*).

For commercially sensitive reasons, we have kept the results of the data of the lasts at the Centre of Rehabilitation Engineering and Orthopaedic Footwear R&D, King's College School of Medicine and Dentistry. **Table 3.5** lists only the differences between the stock model last (H6028) and the modified last (H6028S) measurements, and their averaged differences in each section of measurements together with the total average.

Subject	5D12	Right	left	Average
Length	Foot (stick) length	239	238	238.5
	Medial heel to ball	171	171	171.0
	Medial heel to ankle	60	57	58.5
	Heel to smallest toe	201	199	200.0
	Lateral heel to ball	156	155	155.5
	Lateral heel to ankle	51	49	50.0
Girth	Joint girth	230	229	229.5
	Waist girth	229	226	227.5
	Instep girth	240	238	239.0
Height	Big toe height	22	23	22.5
	1st metatarsal-head height	40	40	40.0
	5th metatarsal-head height	26	25	25.5
	Instep height	64	61	62.5
	Medial malleoli height	88	87	87.5
	Lateral malleoli height	76	73	74.5
Width	Joint width	93	92	92.5
	Seat width	61	60	60.5

Table 3.3: RESULTS OF SUBJECT'S FEET MEASUREMENT (5D12; unit:mm).

ITEMS (mm)	d(H6028S)	d(H6028)
STICK LENGTH	15.5	15.5
MEDIAL HEEL TO BALL	-1.0	-3.0
JOINT GIRTH	-0.5	-11.5
JOINT WIDTH	-9.5	-12.5
SEAT WIDTH	-2.5	-4.5

Table 3.4: DIFFERENCES BETWEEN FOOT & LASTS MEASUREMENTS.

LAST (mm)		d(l)
LENGTH	STICK LENGTH	0
	TOTAL LENGTH	3
	BOTTOM LENGTH	0
	MEDIAL HEEL TO BALL	2
	LATERAL HEEL TO BALL	2
	VAMP LENGTH	1
	AVERAGES	**1.33**
GIRTH	JOINT GIRTH	11
	WAIST GIRTH	11
	INSTEP GIRTH	15
	LONG HEEL GIRTH	10
	SHORT HEEL GIRTH	19
	AVERAGES	**13.20**
WIDTH	TREAD WIDTH	3
	BACKPART WIDTH	4
	HEEL SEAT WIDTH	2
	BACK CONE TOP WIDTH	2
	AVERAGES	**2.75**
HEIGHT	TOE SPRING	0
	TOE DEPTH	0
	HEEL PITCH	0
	BACK CONE HEIGHT	0
	BACKSEAM-TACK HEIGHT	0
	AVERAGES	**0.00**
TOTAL AVERAGES		**4.32**

Table 3.5: THE DIFFERENCES BETWEEN THE MODIFIED LAST (H6028S) AND THE STOCK LAST (H6028) MEASUREMENTS.

3.4.2 Cross-sections

Table 3.6 to **Table 3.9** present the cross-sectional results of the foot and the lasts. These cross-sections are taken at 5 mm intervals from the toe end (*z = -255 mm* of the lasts and *z = -240 mm* of the foot) to the instep (long heel) point (*z = -140 mm*). The results of these cross-sectional areas are listed in **Table 3.6.** The circumferential results are listed in **Table 3.7. Table 3.8** and **Table 3.9** show the results of the depth and width measures. It is unnecessary to take the areas, circumferences, and depth results of cross-sections between instep point (*z = -140 mm*) and back heel point (*z = 0 mm*), except the width measures.

Table 3.10 shows the width measurements from instep point to back heel point. **Table 3.11, 3.12** and **3.13** all include area, circumference, depth and width measurements. **Table 3.11** shows the results of the differences, $d(x_1)$*=H6028S.x-foot.x*, between the cross-sections of the foot and the modified model last. The negative data indicate that the measures of the foot (*foot.x*) are bigger than those of the last (*H6028S.x*). **Table 3.12** shows the results of the differences, $d(x_2)$*=H6028.x-foot.x*, between the cross-sections of the foot and the stock model last. The negative data indicate that the measures of the foot (*foot.x*) are bigger than those of the last (*H6028.x*). **Table 3.13** shows the differences, $d(x_3)$*=H6028S.x-H6028.x*, between the cross-sections of the modified last (*H6028S.x*) and the stock model last (*H6028.x*).

Table 3.14 follows on from **table 3.11, 3.12,** and **3.13**, showing the results of the differences in width measurements. The $d(x_1)$ lists the width differences between modified last (*H6028S.x*) and foot (*foot.x*). The $d(x_2)$ lists the width differences between stock model last (*H6028.x*) and foot (*foot.x*). The $d(x_3)$ shows the width differences between these two model lasts (*H6028S.x* & *H6028.x*). The negative data in $d(x_1)$ & $d(x_2)$ columns indicate that foot measures are bigger than those of lasts.

CROSS-SECTIONS (sq.mm)		AREAS		
		H6028S	H6028	FOOT
Toe Allowances	-255	0.0	0.0	-
	-250	241.5	228.1	-
	-245	608.2	562.9	-
The tip of the toe to 1st Metatarsal-head	-240	884.0	784.9	0.0
	-235	1066.8	977.3	331.0
	-230	1196.4	1118.6	516.6
	-225	1362.7	1252.1	776.6
	-220	1533.8	1414.6	964.8
	-215	1690.6	1550.2	1061.6
	-210	1862.7	1706.0	1067.5
	-205	2018.4	1842.1	1178.1
	-200	2232.3	2042.7	1266.2
	-195	2395.2	2218.5	1642.1
	-190	2616.0	2396.7	1970.3
	-185	2816.0	2604.3	2180.8
	-180	3021.6	2746.9	2372.4
	-175	3184.3	2947.8	2561.9
1st Metatarsal-head	-170	3373.5	3074.0	2715.3
1st to 5th Metatarsal-head	-165	3534.1	3226.5	2873.5
	-160	3679.0	3324.5	2912.2
5th Metatarsal-head	-155	3786.4	3435.9	2996.2
5th Metatarsal-head to Instep (long heel) point	-150	3873.7	3503.2	3017.7
	-145	3875.5	3557.7	3024.5
Instep (long heel) point	-140	3934.7	3555.3	3086.5

Table 3.6: THE RESULTS OF CROSS-SECTION AREAS.

CROSS-SECTIONS (mm)		CIRCUMFERENCES		
		H6028S	H6028	FOOT
Toe Allowances	-255 -250 -245	0.0 59.2 96.3	0.0 58.9 94.3	- - -
The tip of the toe to 1st Metatarsal-head	-240 -235 -230 -225 -220 -215 -210 -205 -200 -195 -190 -185 -180 -175	118.4 133.3 144.2 154.1 164.3 172.7 181.2 186.9 195.4 200.5 206.9 211.2 216.9 219.9	113.7 130.0 140.5 149.8 159.0 167.3 173.7 179.9 186.9 193.4 199.0 203.3 207.3 212.0	0.0 88.0 102.1 129.2 144.8 153.6 172.5 181.4 185.8 195.0 201.9 209.1 214.4 218.8
1st Metatarsal-head	-170	**224.2 (225.0)**	**214.8 (214.5)**	**216.4 (218.0)**
1st to 5th Metatarsal-head	-165 -160	228.5 231.4	218.0 219.8	219.2 220.0
5th Metatarsal-head	-155	**233.4 (234.0)**	**223.6 (221.5)**	**223.4 (224.5)**
5th Metatarsal-head to Instep (long heel) point	-150 -145	235.1 237.0	225.0 227.4	222.9 221.7
Instep (long heel) point	-140	**240.1 (241.5)**	**228.8 (230.0)**	**222.6 (221.5)**

Table 3.7: THE RESULTS OF CROSS-SECTION CIRCUMFERENCES.
The data in the parentheses were taken by hand using measuring tape.

CROSS-SECTIONS (mm)		DEPTH		
		H6028S	H6028	FOOT
Toe Allowances	-255	0.0	0.0	-
	-250	14.0	13.1	-
	-245	19.5	18.2	-
The tip of the toe to 1st Metatarsal-head	-240	21.6	20.2	0.0
	-235	22.5	20.8	16.7
	-230	22.5	21.1	19.7
	-225	24.3	22.6	23.5
	-220	25.5	24.2	25.2
	-215	26.7	25.9	25.9
	-210	28.3	27.1	26.3
	-205	30.5	28.6	26.1
	-200	33.4	31.5	25.2
	-195	34.5	33.5	28.1
	-190	37.5	35.7	31.4
	-185	40.9	39.5	34.8
	-180	43.1	41.4	36.8
	-175	46.8	45.7	39.2
1st Metatarsal-head	**-170**	**50.3 (49.0)**	**48.9 (48.0)**	**44.7 (43.5)**
1st to 5th Metatarsal-head	-165	53.4	51.6	45.0
	-160	58.0	55.1	45.7
5th Metatarsal-head	**-155**	**61.8 (59.0)**	**58.7 (57.5)**	**45.8 (46.5)**
5th Metatarsal-head to Instep (long heel) point	-150	65.4	62.3	46.1
	-145	68.1	66.0	47.9
Instep (long heel) point	**-140**	**72.0 (71.5)**	**68.3 (68.0)**	**49.9 (50.0)**

Table 3.8: THE RESULTS OF DEPTH MEASUREMENTS.
The data in the parentheses were measured by hand using measuring tape.

CROSS-SECTIONS (mm)		WIDTH		
		H6028S	H6028	FOOT
Toe Allowances	-255	0.0	0.0	-
	-250	19.5	19.0	-
	-245	36.0	36.0	-
The tip of the toe to 1st Metatarsal-head	-240	45.5	44.3	0.0
	-235	52.9	51.3	32.8
	-230	58.3	56.2	39.5
	-225	62.8	60.2	53.8
	-220	67.5	64.4	57.9
	-215	70.4	67.2	58.9
	-210	74.3	70.0	68.9
	-205	76.1	73.3	72.7
	-200	79.6	75.6	73.7
	-195	80.5	77.9	81.6
	-190	83.2	79.5	84.7
	-185	84.0	80.8	86.6
	-180	85.2	81.8	88.1
	-175	85.5	81.9	88.7
1st Metatarsal-head	**-170**	**85.5 (85.5)**	**81.9 (82.0)**	**87.4 (88.0)**
1st to 5th Metatarsal-head	-165	85.5	81.9	87.1
	-160	85.5	80.1	87.7
5th Metatarsal-head	**-155**	**84.0 (84.5)**	**79.5 (79.5)**	**88.4 (88.5)**
5th Metatarsal-head to Instep (long heel) point	-150	82.5	77.7	88.6
	-145	79.1	76.0	87.7
Instep (long heel) point	**-140**	**79.0 (79.5)**	**75.1 (75.0)**	**86.3 (86.0)**

Table 3.9: THE RESULTS OF WIDTH MEASUREMENTS. (TAKEN BETWEEN TOE POINT & INSTEP POINT)
The data in the parentheses were measured by hand using measuring tape.

CROSS-SECTIONS (mm)		WIDTH		
		H6028S	H6028	FOOT
Instep (long heel) point to Throat (short heel) point	-135	77.1	72.9	85.7
	-130	75.3	71.0	84.8
	-125	72.8	69.1	83.8
	-120	71.9	68.3	83.1
	-115	69.8	66.9	82.2
	-110	69.5	66.1	82.1
	-105	68.2	65.3	81.6
	-100	66.5	64.8	81.1
	-95	66.5	63.1	79.9
Throat (short heel) point	**-90**	**66.5 (67.0)**	**62.5 (64.0)**	**78.8 (79.5)**
Throat (short heel) point to Medial Malleolus	-85	64.5	62.5	77.2
	-80	64.2	62.2	76.6
	-75	63.5	61.5	74.4
	-70	63.5	61.0	72.2
	-65	63.0	60.8	68.5
	-60	63.0	60.2	66.8
Medial Malleolus	**-55**	**61.8 (62.5)**	**59.5 (60.0)**	**64.2 (66.0)**
Medial to Lateral Malleolus	-50	61.8	59.5	62.6
	-45	61.8	58.8	60.6
Lateral Malleolus	**-40**	**60.5 (61.0)**	**57.5 (58.5)**	**58.8 (61.0)**
Lateral Malleolus to Back Heel point	-35	59.0	55.3	56.2
	-30	57.5	53.5	53.1
	-25	53.5	51.0	49.3
	-20	49.5	46.8	44.6
	-15	43.5	40.5	37.8
	-10	34.5	31.8	29.2
	-5	23.2	22.5	20.3
Back Heel point	0	0.0	0.0	0.0

Table 3.10: THE RESULTS OF WIDTH MEASUREMENTS. (TAKEN BETWEEN INSTEP & BACK HEEL POINT)
The data in the parentheses were measured by hand using measuring tape

CROSS-SECTIONS		$d(x_1)$=H6028S.x-foot.x			
		Areas	Girth	Depth	Width
TOE ALLOWANCES	-255	(0.0)	(0.0)	(0.0)	(0.0)
	-250	241.5	59.2	14.0	19.5
	-245	608.2	96.3	19.5	36.0
THE TIP OF THE TOE to 1st METATARSAL-HEAD	-240	884.0	118.4	21.6	45.5
	-235	735.8	45.3	5.8	20.1
	-230	679.8	42.1	2.8	18.8
	-225	586.1	24.9	0.8	9.0
	-220	569.0	19.5	0.3	9.6
	-215	629.0	19.1	0.8	11.5
	-210	795.2	8.7	2.0	5.4
	-205	840.3	5.5	4.4	3.4
	-200	1066.1	9.6	8.2	5.9
	-195	753.1	5.5	6.4	-1.1
	-190	645.7	5.0	6.1	-1.5
	-185	635.2	2.1	6.1	-2.6
	-180	649.2	2.5	6.3	-2.9
	-175	622.4	1.1	7.6	-3.2
1st METATARSAL-HEAD	-170	658.2	7.8	5.5	-1.9
1st to 5th METATARSAL-HEAD	-165	660.6	9.3	8.4	-1.6
	-160	766.8	11.4	12.3	-2.2
5th METATARSAL-HEAD	-155	790.2	10.0	16.0	-4.4
5th METATARSAL-HEAD to INSTEP point	-150	856.0	12.2	19.3	-6.1
	-145	851.0	15.3	20.2	-8.6
INSTEP (long heel) point	-140	848.2	17.5	22.1	-7.3

Table 3.11: THE DIFFERENCES OF CROSS-SECTION BETWEEN FOOT & LAST(H6028S).

CROSS-SECTIONS		$d(x_2)$=H6028.x-foot.x			
		Areas	Girth	Depth	Width
TOE ALLOWANCES	-255	(0.0)	(0.0)	(0.0)	(0.0)
	-250	228.1	58.9	13.1	19.0
	-245	562.9	94.3	18.2	36.0
THE TIP OF THE TOE to 1st METATARSAL-HEAD	-240	784.9	113.7	20.2	44.3
	-235	646.3	42.0	4.1	18.5
	-230	602.0	38.4	1.4	16.7
	-225	475.4	20.6	-0.9	6.4
	-220	449.8	14.2	-1.0	6.5
	-215	488.6	13.7	-0.0	8.3
	-210	638.5	1.2	0.8	1.1
	-205	664.0	-1.5	2.5	0.6
	-200	876.5	1.1	6.3	1.9
	-195	576.4	-1.6	5.4	-3.7
	-190	426.4	-2.9	4.3	-5.2
	-185	423.5	-5.8	4.7	-5.8
	-180	374.5	-7.1	4.6	-6.3
	-175	385.9	-6.8	6.5	-6.8
1st METATARSAL-HEAD	-170	358.7	-1.6	4.2	-5.5
1st to 5th METATARSAL-HEAD	-165	353.0	-1.2	6.6	-5.2
	-160	412.3	-0.2	9.4	-7.6
5th METATARSAL-HEAD	-155	439.7	0.2	12.9	-8.9
5th METATARSAL-HEAD to INSTEP point	-150	485.5	2.1	16.2	-10.9
	-145	533.2	5.7	18.1	-11.7
INSTEP (long heel) point	-140	468.8	6.2	18.4	-11.2

Table 3.12: THE DIFFERENCES OF CROSS-SECTION BETWEEN FOOT & LAST(H6028).

CROSS-SECTIONS		d(x_3)=H6028S.x-H6028.x			
		Areas	**Girth**	**Depth**	**Width**
TOE ALLOWANCES	-255	(0.0)	(0.0)	(0.0)	(0.0)
	-250	13.4	0.3	0.9	0.5
	-245	45.3	2.0	1.3	0.0
THE TIP OF THE TOE to 1st METATARSAL-HEAD	-240	99.1	4.7	1.4	1.2
	-235	89.5	3.3	1.7	1.6
	-230	77.8	3.7	1.4	2.1
	-225	110.6	4.3	1.7	2.6
	-220	119.2	5.3	1.3	3.1
	-215	140.4	5.4	0.8	3.2
	-210	156.7	7.5	1.2	4.3
	-205	176.3	7.0	1.9	2.8
	-200	189.6	8.5	1.9	4.0
	-195	176.7	7.1	1.0	2.6
	-190	219.3	7.9	1.8	3.7
	-185	211.7	7.9	1.4	3.2
	-180	274.7	9.6	1.7	3.4
	-175	236.5	7.9	1.1	3.6
1st METATARSAL-HEAD	-170	299.5	9.4	1.4	3.6
1st to 5th METATARSAL-HEAD	-165	307.6	10.5	1.8	3.6
	-160	354.5	11.6	2.9	5.4
5th METATARSAL-HEAD	-155	350.5	9.8	3.1	4.5
5th METATARSAL-HEAD to INSTEP point	-150	370.5	10.1	3.1	4.8
	-145	317.8	9.6	2.1	3.1
INSTEP (long heel) point	-140	379.4	11.3	3.7	3.9

Table 3.13: THE DIFFERENCES OF CROSS-SECTION BETWEEN LAST(H6028S) & LAST(H6028).

CROSS-SECTIONS (mm)		WIDTH		
		$d(x_1)$	$d(x_2)$	$d(x_3)$
Instep (long heel) point to Throat (short heel) point	-135	-8.6	-12.8	4.2
	-130	-9.5	-13.8	4.3
	-125	-11.0	-14.7	3.7
	-120	-11.2	-14.8	3.6
	-115	-12.4	-15.3	2.9
	-110	-12.6	-16.0	3.4
	-105	-13.4	-16.3	2.9
	-100	-14.6	-16.3	1.7
	-95	-13.4	-16.8	3.4
Throat (short heel) point	-90	-12.3	-16.3	4.0
Throat (short heel) point to Medial Malleolus	-85	-12.7	-14.7	2.0
	-80	-12.4	-14.4	2.0
	-75	-10.9	-12.9	2.0
	-70	-8.7	-11.2	2.5
	-65	-5.5	-7.7	2.2
	-60	-3.8	-6.6	2.8
Medial Malleolus	-55	-2.4	-4.7	2.3
Medial to Lateral Malleolus	-50	-0.8	-3.1	2.3
	-45	1.2	-1.8	3.0
Lateral Malleolus	-40	1.7	-1.3	3.0
Lateral Malleolus to Back Heel point	-35	2.8	-0.9	3.7
	-30	4.4	0.4	4.0
	-25	4.2	1.7	2.5
	-20	4.9	2.2	2.7
	-15	5.7	2.7	3.0
	-10	5.3	2.6	2.7
	-5	2.9	2.2	0.7
Back Heel point	0	0.0	0.0	0.0

Table 3.14: THE WIDTH DIFFERENCES OF CROSS-SECTIONS BETWEEN FOOT & LASTS. (BETWEEN INSTEP & BACK HEEL POINT)

$d(x_1)$ = H6028S.x - foot.x

$d(x_2)$ = H6028.x - foot.x

$d(x_3)$ = H6028S.x - H6028.x

3.4.3 Volumetric data

The full details of the volumetric results, in which the foot and lasts are divided into 7 parts, are set out from **table 3.15** to **table 3.19(A) & (B).**

Table 3.15 lists the volume of toe allowance, from toe-end ($z = -255\ mm$) of the last to the longest toe ($z = -240\ mm$) of the foot.

Table 3.16(A) shows the volume of the toe region (without toe room allowance) from the longest toe to the 1st metatarsal-head ($z = -170\ mm$). In **table 3.16(B)**, the volume consists of the toe section and the toe allowance, calculated between toe-end of the last and the 1st metatarsal-head.

Table 3.17 lists the volumetric data of the joint region which is calculated between the 1st and the 5th ($z = -155\ mm$) metatarsal-head.

The volumetric data of the waist-instep region, from the 5th metatarsal-head to the instep point ($z = -140\ mm$), is listed in **table 3.18.**

Table 3.19(A) and **table 3.19(B)** list the calculated volumetric data of the whole forepart regions. The volume of the forepart in **table 3.19(A)** is taken from the longest toe ($z = -240\ mm$) of the foot to the instep point ($z = -140\ mm$). In **table 3.19(B)**, the volume is taken between the toe-end ($z = -255\ mm$) of the last and the instep point, including the toe allowance.

255-240 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	0	0	0
H6028	7,471	3,955	5,713
H6028S	8,427	4,249	6,338

Table 3.15: THE VOLUME OF TOE ALLOWANCE.(from -255 mm to -240 mm)

240-170 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	102,195	88,950	95,573
H6028	139,459	128,014	133,737
H6028S	151,852	139,404	145,628

Table 3.16(A): THE VOLUME OF TOE REGIONS FROM TOE TIP TO BALL EXCLUDING TOE ALLOWANCE.(from -240 mm to -170 mm)

255-170 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	102,195	88,950	95,573
H6028	146,930	131,969	139,449
H6028S	160,279	143,653	151,966

Table 3.16(B): THE VOLUME OF TOE REGIONS FROM TOE-END TO BALL INCLUDING TOE ALLOWANCE.(from -255 mm to -170 mm)

170-155 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	43,910	42,505	43,208
H6028	49,935	48,125	49,030
H6028S	54,998	52,933	53,966

Table 3.17: THE VOLUME OF JOINT REGIONS. (from -170 mm to -155 mm)

155-140 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	45,644	45,192	45,418
H6028	53,081	52,484	52,783
H6028S	58,420	57,678	58,049

Table 3.18: THE VOLUME OF WAIST & INSTEP.(from -155 mm to -140 mm)

240-140 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	191,748	176,647	184,198
H6028	242,475	228,623	235,549
H6028S	265,269	250,015	257,642

Table 3.19(A): THE VOLUME OF FOREPART EXCLUDING TOE ALLOWANCE. (from -240 mm to -140 mm)

255-140 (cu.mm)	Parallel Cross-sections		
	V_{max}	V_{min}	V_{mean}
FOOT	191,748	176,647	184,198
H6028	249,946	232,578	241,262
H6028S	273,696	254,264	263,980

Table 3.19(B): THE VOLUME OF FOREPART INCLUDING TOE ALLOWANCE. (from -255 mm to -140 mm)

3.4.4 Surface areas

As for the volumetric data, the surface area is also divided into 7 parts, the results being set out from **table 3.20** to **table 3.24(A) & (B)**. **Table 3.20** lists the surface area data of the toe allowance, between the toe-end (z = *-255 mm*) of the last and the longest toe (z = *-240 mm*) of the foot.

Table 3.21(A) presents the surface area of the toe region, without toe allowance section, from the longest toe to the 1st metatarsal-head (z = *-170 mm*). In **table 3.21(B)**, it consists of the toe section and the toe allowance, calculated between toe-end and the 1st metatarsal-head.

Table 3.22 lists the surface area data of the joint region, calculated between the 1st and the 5th (z = *-155 mm*) metatarsal-head.

The area value of the surface in the waist-instep region, from the 5th metatarsal-head to the instep point (z = *-140 mm*) is listed in **table 3.23.**

Table 3.24(A) and **table 3.24(B)** list the calculated surface area data of the whole forepart regions. The surface area of the forepart in **table 3.24(A)** is from the longest toe (z = *-240 mm*) of the foot to the instep point (z = *-140 mm*). In **table 3.24(B),** it is between the toe-end (z = *-255 mm*) of the last and the instep point, including the toe allowance.

255-240 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	0	0	0
H6028	1,335	766	1,051
H6028S	1,370	778	1,074

Table 3.20: THE SURFACE AREA OF TOE ALLOWANCE.
(from -255 mm to -240 mm)

240-170 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	11,977	10,983	11,480
H6028	12,587	12,081	12,334
H6028S	13,059	12,530	12,795

Table 3.21(A): THE SURFACE AREA OF TOE REGIONS FROM TOE TIP TO BALL EXCLUDING TOE ALLOWANCE.(from -240 mm to -170 mm)

255-170 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	11,977	10,983	11,480
H6028	13,921	12,847	13,384
H6028S	14,428	13,307	13,868

Table 3.21(B): THE SURFACE AREA OF TOE REGIONS FROM TOE-END TO BALL INCLUDING TOE ALLOWANCE.(from -255 mm to -170 mm)

170-155 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	3,313	3,278	3,295
H6028	3,307	3,263	3,285
H6028S	3,467	3,421	3,444

Table 3.22: THE SURFACE AREA OF JOINT REGIONS BETWEEN 1st & 5th METATARSAL-HEAD. (from -170 mm to -155 mm)

155-140 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	3,336	3,340	3,338
H6028	3,406	3,380	3,393
H6028S	3,561	3,528	3,545

Table 3.23: THE SURFACE AREA OF WAIST & INSTEP. (from -155 mm to -140 mm)

240-140 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	18,626	17,601	18,114
H6028	19,300	18,724	19,012
H6028S	20,086	19, 478	19,782

Table 3.24(A): THE SURFACE AREA OF FOREPART EXCLUDING TOE ALLOWANCE. (from -240 mm to -140 mm)

255-140 (sq.mm)	SA_{max}	SA_{min}	SA_{mean}
FOOT	18,626	17,601	18,114
H6028	20,634	19,490	20,062
H6028S	21,456	20,255	20,856

Table 3.24(B): THE SURFACE AREA OF FOREPART INCLUDING TOE ALLOWANCE. (from -255 mm to -140 mm)

3.5 Analysis and discussion

3.5.1 Cross-sectional data

Although the cross-sectional data are taken from toe-end (*z= -255 mm*) to back-heel (*z= 0 mm*) both on lasts and foot model, as can be imagined, the shoe is not a sealed container. There is an opened topline to let the foot in. In this trial, the forepart topline point is marked at the instep point (*z= -140 mm*) dividing the lasts and the foot model into two parts. The cross-sectional data of areas, girth, and depth are calculated at the forepart region only. For seat design demand, the cross-sectional data of width are used both from the forepart and the backpart. The compared differences of the forepart cross-sectional data (ie. areas, girth, depth, and width) are summarised as follows:

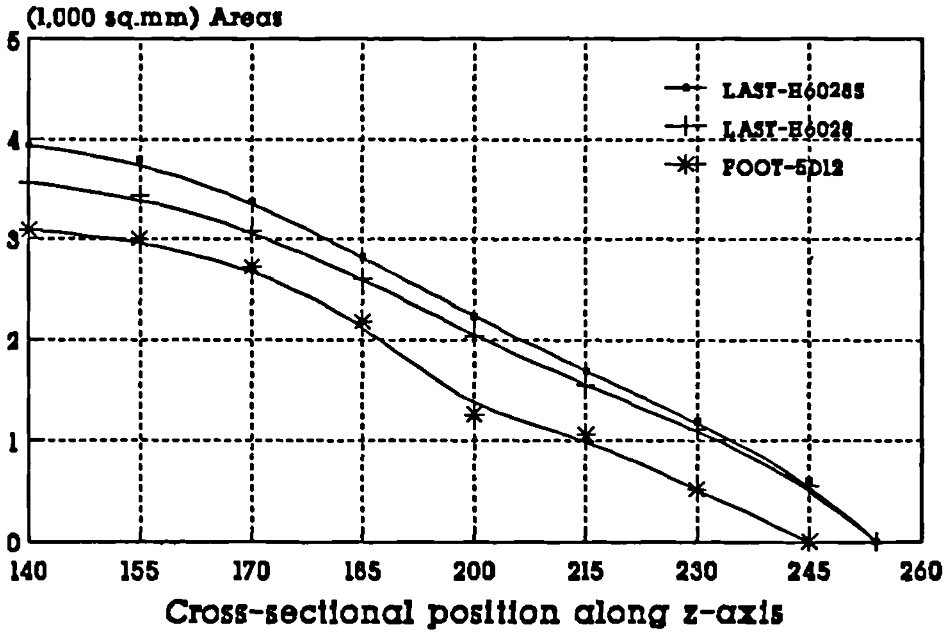

Figure 3.11(A): THE CROSS-SECTIONAL DIFFERENCES BETWEEN LASTS & FOOT (AREAS). FROM *z= -140 mm* TO *z= -260* AT 15 mm INTERVALS.

(1) Areas: The relationship between cross-sectional areas and stick length is illustrated as 3.11(A). All the cross-sectional areas of foot-5D12 are smaller than those two model lasts. Calculated on the cross-sectional forepart, without toe allowance (from *z= -240 mm* to *-140 mm*), the area of the modified last-H6028S is on average about 30.7% bigger than that of the foot-5D12, and the area of the stock last-H6028 about 19%

bigger than that of the foot-5D12. Comparing the two model lasts, the modified last-H6028S is about 9.8% bigger than the stock last-H6028.

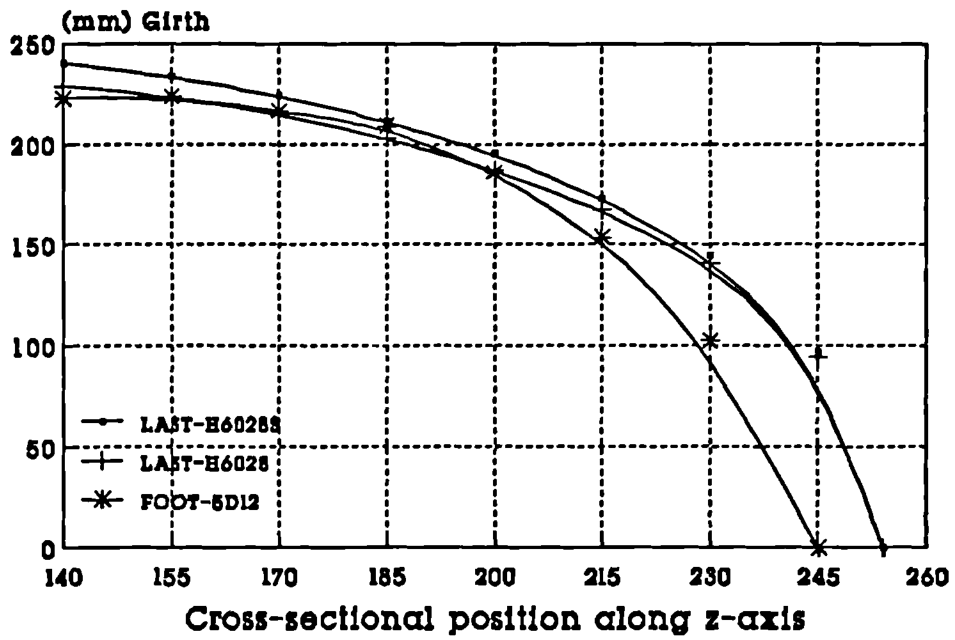

Figure 3.11(B): THE CROSS-SECTIONAL DIFFERENCES BETWEEN LASTS & FOOT (GIRTH). FROM *z= -140 mm* TO *z= -260 mm* AT 15 mm INTERVALS.

(2) Circumferences: The relationship between cross-sectional girth and stick length is illustrated as **figure 3.11(B)**. The total average of the cross-sectional girth (circumferences) of the last-H6028S is about 6.1% bigger than that of the foot. In the case of last-H6028, the girth is about 1.7% on average bigger than that of the foot. Unlike last-H6028S, the averaged girth measurement of last-H6028 is about 0.3% smaller than that of foot-5D12 at the joint region (*z= -170 mm* to *-155 mm*). Comparing the two model lasts, the averaged girth measurement of modified last-H6028S is about 4.1% longer than that of stock last-H6028. This indicates that in the case of the made to measure orthopaedic shoe last there is a special last girth allowance required, an additional 4-6% of the girth measures.

(3) Depth: On average, the depth of last-H6028S is about 28.4% greater than that of the foot. This includes 15.6% at the toe, 23.4% at the joint, and 40.9% at the waist-instep region. Last-H6028 is about 23% deeper than that of the foot with 10.8% at the toe, 18.3% at the joint, and 34.6% at the waist-instep region. Obviously, differences of depth data at the waist-instep region between foot and lasts tend to be sharp, the explanation being that shoe last shape is not a copy of a foot (see **figure 3.11(C)** for the details of the relationship between the cross-sectional depth and stick length).

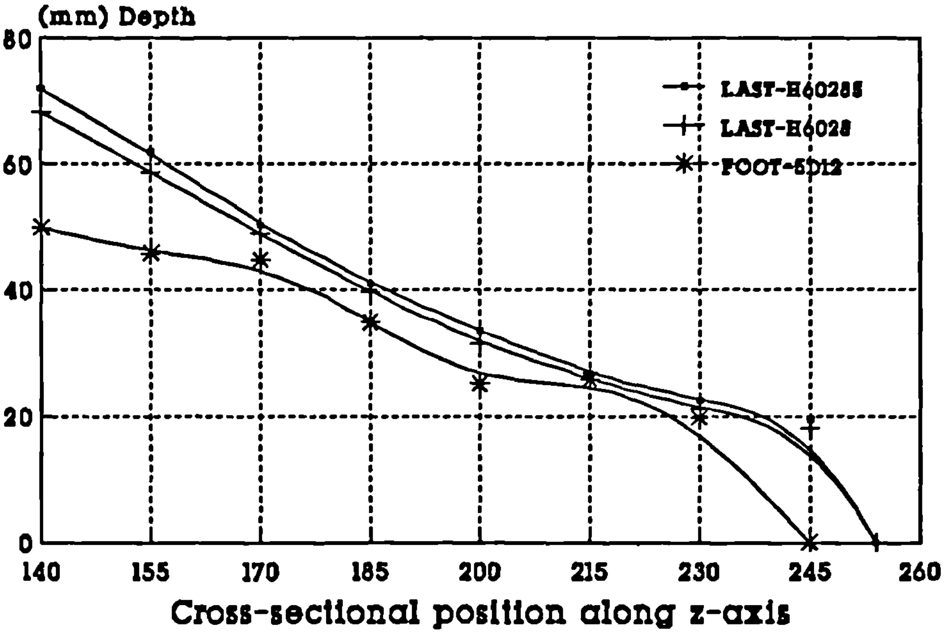

Figure 3.11(C): THE CROSS-SECTIONAL DIFFERENCES BETWEEN LASTS & FOOT (DEPTH). FROM *z= -140 mm* TO *z= -260 mm* AT 15 mm INTERVALS.

(4) **Width:** The relationship between cross-sectional width and stick length is illustrated as **figure 3.11(D)**. The cross-sectional width is taken from both the forepart and backpart of the foot, ie. from the longest toe (*z= -240 mm*) to the back-heel point (*z= 0 mm*). Taking the averaged totals, the width of last-H6028S is about 6.3% less (narrower) than that of the foot, including 2.9% at the joint, 7.5% at the waist-instep, 14.5% at the instep-throat, 11.9% at the throat-ankle, 0.2% at the ankle region. The exceptions are at the toe region where the last is 7.2% wider and the ankle-heel region (9.2% wider). With last-H6028, the averaged width is about 8.6% less than that of the foot. Most of the cross-sectional measurements in both lasts are narrower than those of the foot, except for two regions (ie. toe region and ankle-heel region) where they are wider.

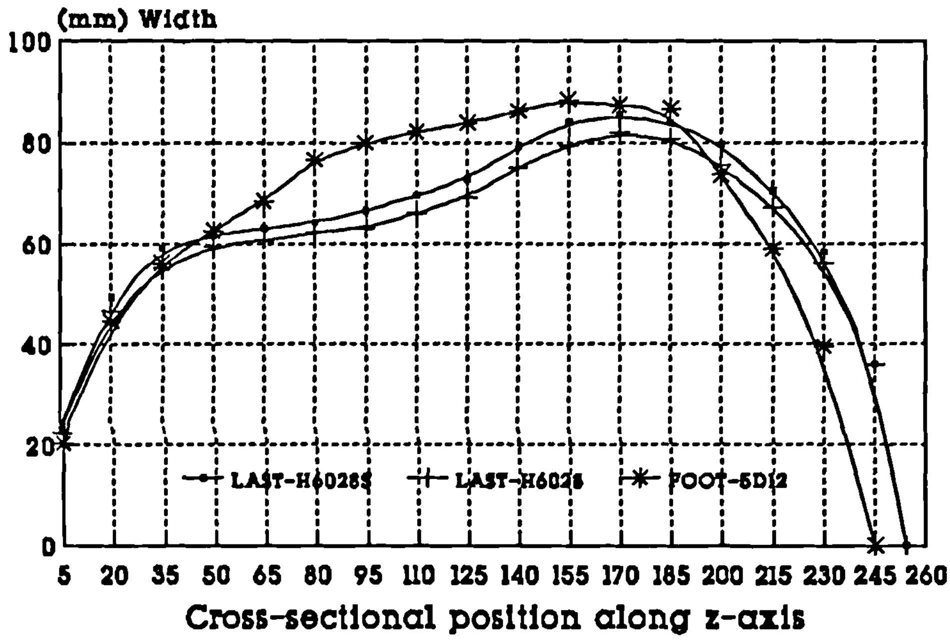

Figure 3.11(D): THE CROSS-SECTIONAL DIFFERENCES BETWEEN LASTS & FOOT (WIDTH). FROM $z= -140$ *mm* TO $z= -260$ *mm* AT 15 mm INTERVALS.

Based on these compared results, the areas of both lasts are much greater than that of foot but the girth measurements are very similar. This is interesting because it has implications for girth measurement and its related shape. For example, we can draw a square shaped area with circumference of **220 mm**, which is about the joint girth[12] measurement of a women's size 5D foot. The area of this square is **3025 sq.mm.** If both a circle and a rectangle shapes of their areas were made with the circumference of **220 mm** (with the same perimeters as the square), then the contained area of the circle[13] would be over **3851 sq.mm**, ie. about **826 sq.mm** of area greater than the square, and the area of the rectangle[14] would be **2400 sq.mm**, ie. about **625 sq.mm** of area smaller than the square. These cross-sectional area changes above prove that the

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[12] The circumference of this subject's 1st metatarsal-joint girth is 219 mm (z= 170 mm), and its cross-sectional area is 2561.9 sq.mm. (measured by CAD/CAM 3D digitiser).

[13] The radius of the circle would be 35.014 mm, and the area of the circle is obtained by squaring the radius and multiplying the Ludolphian number, which is 3.141592654.

[14] The dimension of the rectangle would be 80 mm wide by 30 mm high.

girth measures, which are taken by measuring any part of the foot, are not enough to determine the shape of the foot.

In addition, the increment/decrement between two neighbouring girth fittings is $^1/_4$ inch (about 6 mm) which is $^1/_3$ of the increment/decrement (about 2 mm) in tread width and $^2/_3$ (about 4 mm) in the upper. When applied to the rectangle above, in the case of one fitting **up** (eg. from *D* to *E fitting*), the contained area will increase from 2400 to 2542 sq.mm, about 142 sq.mm; in the case of one fitting **down** (eg. from *D* to *C fitting*), it will decrease from 2400 to 2262 sq.mm, about 138 sq.mm. This indicates that in common girth grading system, one fitting up/down will increase/decrease about **140 sq.mm** in cross-sectional area.

3.5.2 Cross-sectional contour:

Figure 3.12 shows the positions where the cross-sectional contours were taken from toe-cap region (*z= -230 mm*) to throat point (*z= -95 mm*) at 15 mm intervals. **Figure 3.13 to figure 3.22** illustrates these compared cross-sectional contours of foot, last-H6028S and last-H6028 at the forepart region. In these cross-sectional figures, the foot is represented by a dotted line, the made to measure last-H6028S is drawn by a continuous solid line and the original stock last-H6028 is drawn by mixed (segmental) line.

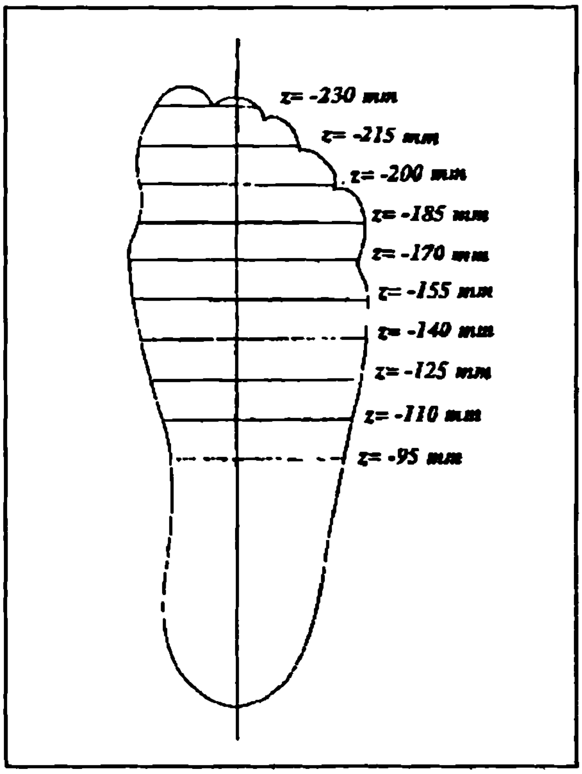

Figure 3.12: CONTOUR POSITIONS.

<u>(1) Toe-cap/1 & 2</u>:

The position of **toe-cap/1** is about 230 mm measured from the back heel point. The cross-section passes over the big (first) and second toes (see **figure 3.13**). **Toe-cap/2** position is about 215 mm from the back heel point. The cross-section passes over the big, 2nd and 3rd toes (see **figure 3.14**). The "**P**" indicates that it might cause some degree of the compressive pressure on the skin of the foot and the "**R**" indicates an area of excessive relief over the foot.

Sometimes, the comparison may be affected by toe-spring. The last cross-sections can be adjusted straight downward in accordance with the centre-line for the better relationship. The contours indicate that some materials at the lateral toe-cap region can be removed or modified to make the model last narrower and less deep.

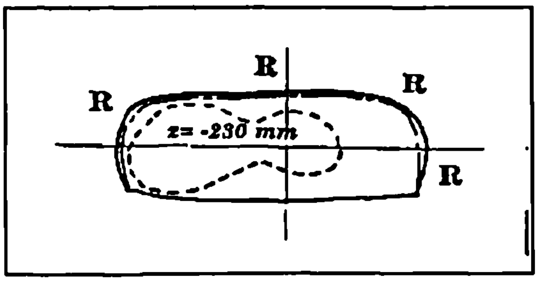

Figure 3.13:
TOE-CAP/1 AT $z = -230$ *mm.*

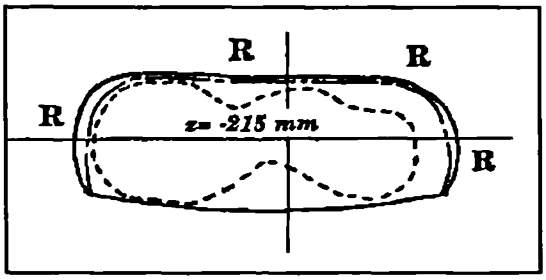

Figure 3.14:
TOE-CAP/2 AT $z = -215$ *mm.*

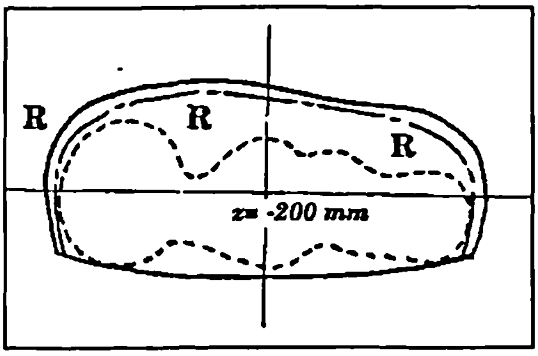

Figure 3.15:
BIG-TOE AT $z = -200$ *mm.*

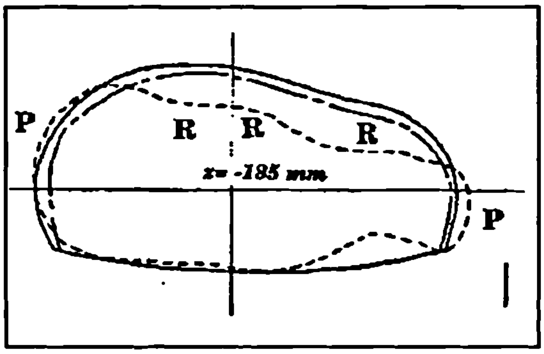

Figure 3.16:
LITTLE-TOE AT $z = -185$ *mm.*

<u>(2) Big & Little-toe:</u>

The position of **big-toe** (at approximately the inter-phalangeal joint of hallux) is about 200 mm from the back heel point, and the contour passes over the big, 2nd, 3rd and 4th toes (see **figure 3.15**). By looking at these cross-sections, it is clear that at the medial part there is a good fit. At the toe-cap regions, some materials at the lateral upper can be removed or modified. **Little-toe** position (at approximately the proximal inter-phalangeal joint of 5th toe) is about 185 mm from the back heel point. The contour passes over the hallux proximal phalangeal shaft and the 5th proximal inter-phalangeal joint. There is mis-alignment between the foot and the lasts on both the medial and lateral swells (side-walls). Although the shoe will distort to accommodate the foot (ie. the allowance space inside the last border is greater than the mis-aligned area of the foot, see **figure 3.16**), it was thought that the foot would be mis-aligned in the shoe with compressive pressure on the toes especially on the little (5th) toe. In a well-designed shoe, there is no pressure on the toes, which should be left free to perform their function.

<u>(3) 1st & 5th Metatarsal-head:</u>

The **1st metatarsal-head** position is about 170 mm from the back heel point. The contour passes over the 1st metatarsal-head point and makes a right-angle with the centre-line (see **figure 3.17**). Similarly, the **5th metatarsal-head** position is about 155 mm from the back heel point and its contour passes over the 5th metatarsal head point and transverses the centre-line at a right-angle (see **figure 3.18**).

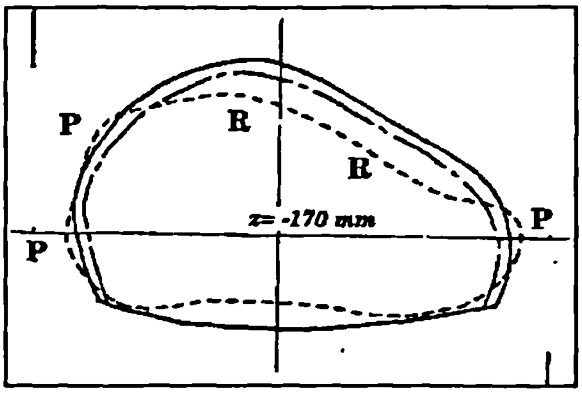

Figure 3.17: 1st METATARSAL-HEAD AT *z= -170 mm.*

Shape fitting in the region of the metatarsal-heads is very important. This is influenced by the relationship between shoe and last fit and the mechanical flexibility and function of the shoe and foot. To ensure full function, the joint area of the shoe should be fitted without pressure across or on the top of the metatarsal joints of the foot, and without so much surplus materials which can

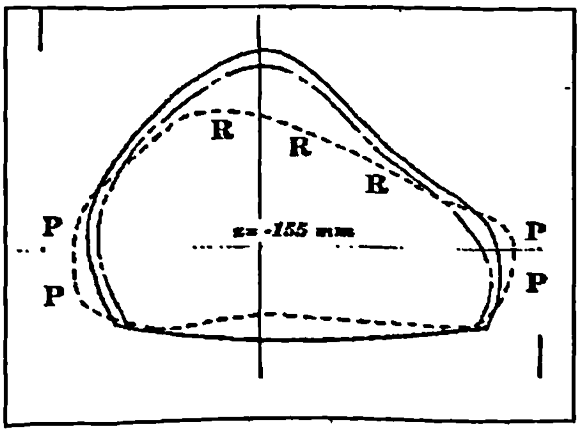

Figure 3.18: 5th METATARSAL-HEAD AT *z= -155 mm.*

cause excessive creasing. Many shoes are liable to return to their former (before lasted) shapes which are narrower and deeper than the last (and foot) shapes, especially in the joint region. This problem results from lack of sufficient heat setting. Such shoes would cause excessive compression from side wall, sometimes leading to discomfort.

(4) Instep:

The position of **instep** is about 140 mm from the back heel point. This contour passes over the point of dorsal articulation between the 1st metatarsal and the medial cuneiform bone (see **figure 3.19**). Comparing the cross-sections, the differences are mis-alignment on the wall area and the height of the forepart cone area. This indicates that the shoe will be tight at the instep-wall and too loose at the instep-cone areas.

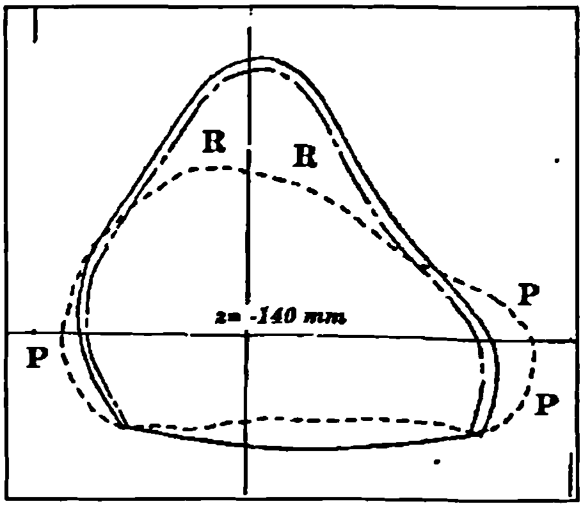

Figure 3.19: INSTEP AT *z= -140 mm.*

Although the shoe will distort to accommodate the foot, it was thought that the foot would be mis-aligned in the shoe with excessive compression on the instep-swell area (as mentioned in metatarsal-head regions). There would also be an excessive looseness at the instep-cone area. In this case, the foot can slip and slide around in shoes, causing friction and irritation to the skin. This can encourage the formation of blisters or callous, both of which may then lead to ulceration in an at risk foot (**Boulton et al, 1988a**) eg. a diabetic patient with reduced sensation.

(5) Instep-Throat:

In the same way as the contour at the instep position, the contours between instep and throat points (see **figure 3.20** and **figure 3.21**) show that there is excessive compression on the side wall area and excessive looseness in the front cone area, both of which may also lead to ulceration. "T" assumes the approximate topline positions in these cross-sections.

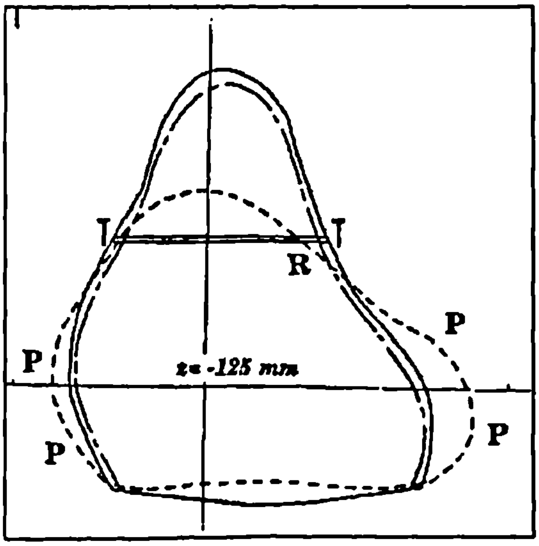

Figure 3.20:
INSTEP-THROAT/1 AT z= *-125 mm.*

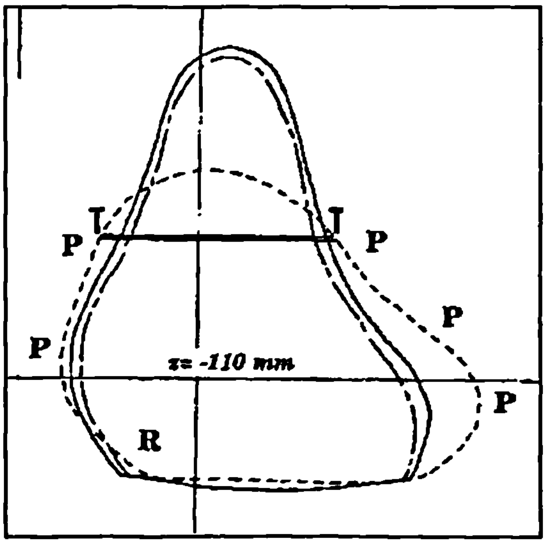

Figure 3.21:
INSTEP-THROAT/2 AT z= *-110 mm.*

(6) Throat:

The position of **throat** is about 95 mm from the back heel point. This contour passes over the dorsal talo-navicular articulation (**figure 3.22**). There is mis-alignment between the foot and the lasts. Fortunately, with the exception of boots, most of the contours, which are taken from the shoes, have open toplines (ie. from the medial topline through the bottom to the lateral topline), which enable the shoes to be more flexible in accommodating the foot. "T" assumes the approximate topline positions in these cross-sections.

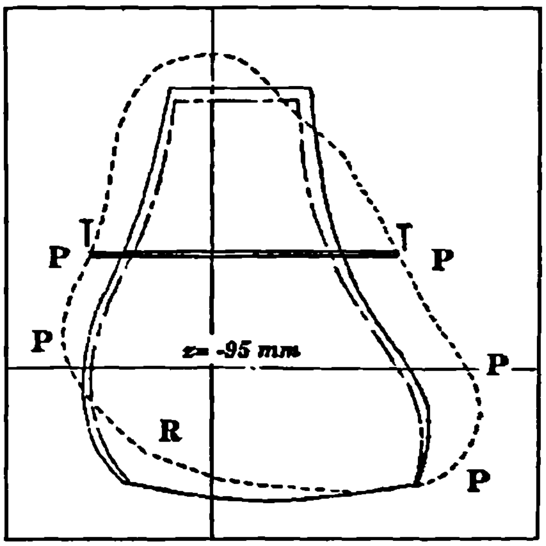

Figure 3.22: THROAT AT z= *-95 mm.*

3.5.3 Volume and surface area data

In this trial, we use Parallel Cross-sectional theorem to calculate the volume of the last and foot. There exists a volumetric discrepancy in each slice between maximum volume V_{max} and minimum volume V_{min}. If the thickness $d(z_i)$ of these slices is minimized, the volumetric discrepancy between V_{max} and V_{min} would become diminishingly small. So the total volume V of the last or foot can be calculated. Also, with the surface areas data, the total surface area of the last or foot, SA, should be as same as SA_{mean}, SA_{max}, and SA_{min}.

3.6 Conclusions

A new method of investigating the relationship between foot shape and shoe last shape has been presented. This method has been designed by the comparison of volumetric data, surface areas and their derived cross-sectional data from the foot and last. This study shows the potential value of using the newly developed 3-D digitiser as an accurate technique for measuring the required areas and circumferences. One advantage of this technique is the application of limits for taking the volume, by mean-value approach. Although we used simple approach, in which we did not take enough cross-sections to minimize the discrepancy of the volumetric data, it appears that this method may prove useful for investigating the relationship between foot and last shape. This technique may also be applicable to other studies.

In general, the foot is gradually wider than those two model lasts from the little toe section to the throat point section. From this point of view, these wider part of the foot might cause some degree of the pressure on the skin at the swell (side-wall) regions of the foot. These pressures might be acceptable in the normal foot but might not be allowed in patients with diabetic foot problems. Although, the model last-H6028S was made to measure using the method of orthopaedic shoe last making, allowing enough space to accommodate the foot, there is still some mis-fit between foot and the shoe last. This indicates that the existing measuring systems for the orthopaedic footwear are not sufficient to support and interpret the relationship between the shape of foot and shoe last. The factor of shape ought to be considered for the shoe fitting and last assessment.

CHAPTER 4
SHELL SHOE FITTING

4.1 Introduction

There are two types of factors which affect the perceived fit of a pair of shoes on any individual. The most obvious ones are attributable solely to the shoe, and relate to its size and material properties. Also important are the subjective requirements which relate to the individual's characteristics of degree of flexibility of foot, subjective preference for tightness and pathology giving special problems such as hypersensitivity.

Last shape and shoe construction are the two most important factors for determination of the shoe-related factors. Without the subjective factors, one might hypothesise an absolute relationship between the last shape and the shape of the foot for any given construction. Then it should be possible to select the correctly fitting shoe by taking foot measurements, and matching these to the last measurements. However, as everyone knows, this presents problems, which might be due to the inadequacies of the measurement systems to represent the shape, or to the subjective factors. Therefore at present it is necessary to undertake fit assessments.

In the volume trade, the normal foot measures taken in a high street shoe shop are only adequate to allow the assistant to select the size of a trial pair or the different construction of the shoes from the shop stock. Those are not sufficient to guarantee a fit with any degree of certainty. The customer must try on the shoes, and a fit assessment is usually made subjectively with perhaps some assistance from the fitter, who can check the basic shoe length, heel fit for slipping, topline for gaping, the toe allowance, the girth fit, and the facing proximity. The choice of shoes is largely limited to those in stock which can be tried on. Only occasionally do the shop order a pair from the suppliers on the basis of trying on a shoe of the adjacent size.

Fit assessments also occurs at the design stage for new shoe styles. Before a pair of new design of shoes is adopted, assessing the last fit must be the first priority at this stage. Fit assessment is made on the basis of trial shoes constructed over the new last, and this is done at least three times on average. This must present a costly and time consuming exercise for footwear manufacturers.

In the orthopaedic shoe trade in the UK, bespoke shoes are made to measure or cast, and usually sent for fitting at the stage of rough finishing, i.e. with the uppers tacked in place and a temporary sole attached. However in the Netherlands it has been observed that the fit assessment is made on the basis of a shell shoe, made by vacuum-moulding suitable PVC materials over the last to form a temporary shoe. This has the advantage that the shoe need not be constructed before fit assessment is made, which reduces both the cost and delays in achieving the final shoe.

There is no doubt that shell shoes fitting assesses solely the shoe fit factor attributable to the last shaping, whereas the sample shoe (or part-finished shoe) fitting gives an assessment of both shoe last shape and shoe construction factors. The advantages already identified for shell shoe fitting vs. sample shoe fitting can be listed as:

- decouples the shoe last shape and construction factors.
- since transparent, gives better ability to assess fit visually than a shoe.
- by the shoe-fitter (or orthotist) marking on the shell shoe, provides better information as a basis for any re-work required.
- is cheaper and easier to ship to the fitting service (or clinic).
- allows fit to be achieved before the patterns of shoes are made.

However the shell shoe fitting does not allow to evaluate the shoe construction factors by which is meant style, materials, and fabrication technique, etc. The study described is a first step towards understanding the significance of the choice more fully. It is also an objective assessment of the technique. The contribution to fit of the relationship between the dimensions of the last and the foot dimensions are also explored as a background.

4.2 Aims and objectives

The general aims of this study[1] are to generate procedures and assess strengths and limitations of assessing the contribution of last shape on shoe fit.

The specific objectives of the study are:

- To compare assessment of fit by shell shoes and normal shoes for normal subjects.
- To document a procedure for assessing shell shoes fitting.
- To identify limitation of shell shoes fitting.
- To separate fit factors due to last shaping from those due to shoe construction.
- To relate fit assessments to foot and last measurements

[1] This study is associated with EUREKA PROJECT "SELECT". This study has been presented at **7th World Congress of the International Society for Prosthetics and Orthotics** (ISPO), Chicago, USA., on June 28th - July 3rd, 1992.

In order to ensure that the whole procedures of the methods are available for application to orthopaedics from the results of normal subjects' trial.

The measuring items were selected as shown in Appendix IV-II.

4.3 Trial protocol

The stages in this trial can be identified as:

- Development of foot measurement system and preliminary intra-observer and inter-observer testing.
- Subjects selection and foot measurement.
- Shoe styles selection and lasts measurement.
- Shell shoes making.
- Fitting trial:
  (1) Shell shoe fitting.
  (2) Shoe fitting.

4.3.1 Foot measurement system and observer tests

A foot measurement system was adopted based on the orthopaedic standard BS-5943 (**British Standard Institution, 1980**) and the Clarks (C&J Clarks International Ltd.) system commonly used in fitting trials. These have both been described in *Chapter 2, Section 2.4*. In order to assess operator consistency, a trial was conducted involving **J. Talbot** (JT), the experienced Head of Fitting Department of C&J Clarks and **R. Chen** (RC), the researcher who would subsequently take the measures and who has received formal training offered to Clarks staff.

Intra-observer tests were conducted by **RC**, who took measurements on a single subject three times over the course of a day. Inter-observer tests were done by both fitters (**JT & RC**) who took measurements on the same subject without reference to each other and compared the results. Before the measurements were taken, the reference points of joint (1st & 5th metatarsal-head), instep (dorsal medial cuneiform-head) and short-heel (talo-navicular joint) point were determined and marked on the subjects' feet in order to ensure the same location for the measurements. The intra-observer and inter-observer tests were performed as described in **figure 4.1** (see *Appendix IV-I* for the details of the measurements of results).

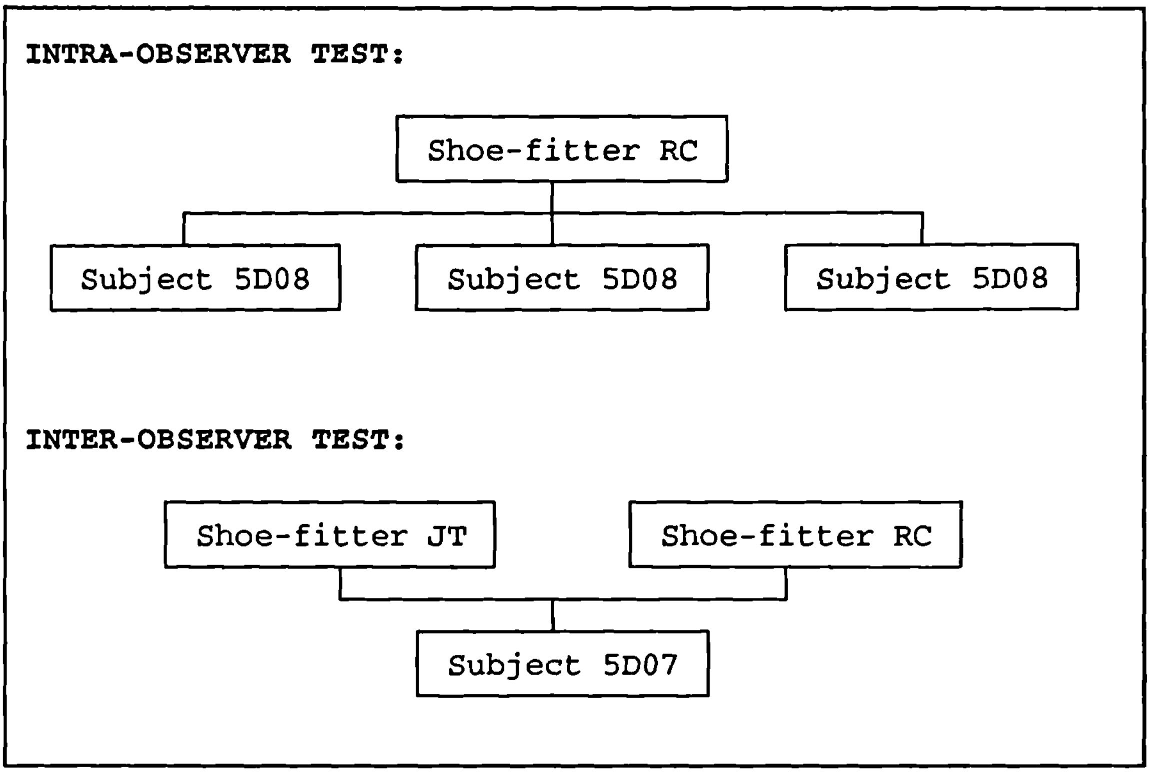

Figure 4.1: OBSERVER TESTS.

4.3.2 Subjects selection and foot measurement

C&J Clarks International Ltd. provided 18[2] usual fitting trial volunteer subjects, 8 subjects in age group 16-25, 5 subjects in age group 26-35, 3 subjects in age group 36-45, and 1 subject each in age group 46-55 and 56-65. Their feet were measured by methods similar to those used in the volume shoe manufacture and orthopaedic trade, including length, girth, height, width measurement and the drawing of an outline diagram (see *Appendix IV-II* for details of the foot measuring items). The volunteers are all known to represent a good average of a given size, in this case ten of size 5D, eight of size 4E and one of size 3F[3].

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[2] Clarks provided a total of 19 volunteer subjects. There is one subject of nominal size 3F, whose foot measures are used for reference only.

[3] It can be noted that according to the UK sizing system the joint girths of these three sizes (5D, 4E and 3F) should be identical, differing only in length (see *Chapter 2: Section 2.6*).

4.3.3 Styles selection and lasts measurement

The shoes were selected from C&J Clarks' current range, of similar design to those used in orthopaedics, eg. **low-heeled** (heel pitch height lower than 1 $^1/_2$ inch) shoes with **fastening over the instep.** Both shoes and their lasts are available from the **stock** and were obtained. There were 10 subjects of nominal size 5D (5D01 to 5D10) who trialled each of three styles (2nd Nature, Nocturne and Ohio), with the exception of three subjects who trialled only two styles because one style was not available (see **table 4.1** for detail). A further eight subjects of nominal size 4E (4E01 to 4E08) trialled a single different style (Pop-life).

	2nd NATURE (Last-8933)	**NOCTURNE (Last-8892)**	**OHIO (MOC) (Last-9036/2)**	**POP-LIFE (Last-8676D)**
4E01				*
4E02				*
4E03				*
4E04				*
4E05				*
4E06				*
4E07				*
4E08				*
5D01	*	*	*	
5D02	*	*	*	
5D03	*	*		
5D04	*	*		
5D05	*	*		
5D06	*	*	*	
5D07	*	*	*	
5D08	*	*	*	
5D09	*	*	*	
5D10	*	*	*	

Table 4.1: THE SPECIFICATION OF TRIALLED STYLES.

All the selected lasts have been measured entirely. A new last measurement chart was developed for entering the measures of these lasts (see *Appendix IV-III* for the details

of the last measurement chart). For commercially sensitive reasons, we withhold all the results of the data of the lasts[4]. Measurements taken and recorded on the chart were:
Length measurements: (a) Stick length; (b) Total length; (c) Bottom length; (d) Medial heel to ball length; (e) Lateral heel to ball length; (f) Vamp length;
Girth measurements: (g) Joint girth; (h) Waist girth; (i) Instep girth; (j) Long heel girth; (k) Short heel girth;
Width measurements: (l) Tread width; (m) Backpart width; (n) Heel seat width; (o) Back cone top width;
Height measurements: (p) Toe spring; (q) Toe depth; (r) Heel pitch height; (s) Back cone height; (t) Backseam-tack height;
Featherline (bottom): (u) Forepart centre-line; (v) Heel seat centre-line; (w) Bottom centre-line; (x) Tread line.

4.3.4 Shell shoes production and properties

The shell shoes were constructed for each selected style and size. These were made of a transparent material with a temporary sole unit (the same sole unit as used on the ordinary shoe) incorporated, using a more rigid thin plastic for the heel area extending down around the walls of the vamp, quarter, and counter; and more flexible material over the top of the vamp. It was possible to walk a little in some of these shoes. These shells were made at Blisters (UK) PLC., Midsomer Norton, Bath and C&J Clarks International Ltd., Street, Somerset, using a similar method to the Dutch Orthopaedic Trade. The materials of the shells include: (1) 2000 micron transparent soft PVC sheet (available from Vink Export Company in Belgium); (2) 500 micron transparent rigid PVC sheet (available from Darvic Company in UK.); (3) SA23 cement; (4) Lasts: chosen from Clarks' current range; (5) Insoles; (6) Outsoles (Units); (7) Inserts as required.

To make the shell shoes, a vacuum forming machine is required (special vacuum forming machine available from Minke Company in Germany). SATRA footwear

[4] We have kept the results of the data of the lasts at the Centre of Rehabilitation Engineering and Orthopaedic Footwear R&D, King's College School of Medicine and Dentistry.

technology centre provided a smaller motorised vacuum former (model: STM-330), the closed dimensions of which are 54cm long, 28cm wide and 32cm in height, a size which enables shell shoes to be made without wasting material. However, the heater is not strong enough to soften the shell upper. After the heater has been improved, this model will be very good for this trial. The shell shoe making procedure is specified as follows:

Bottom making:

(1) Fix the 500 micron rigid PVC sheet to the frame under the heater; (2) Fix the last (stuck with insole) firmly with the bottom up position in the vacuum forming machine; (3) Press the heated and softened rigid PVC sheet downward to cover the last; (4) Turn the vacuum on to shape the bottom of the last; (5) Turn the vacuum off; (6) Cut the bottom with the wall areas kept; Always , cut "V" shaped notches (**figure 4.2**) on the wall at both the medial and lateral joint to ensure flexibility during walking.

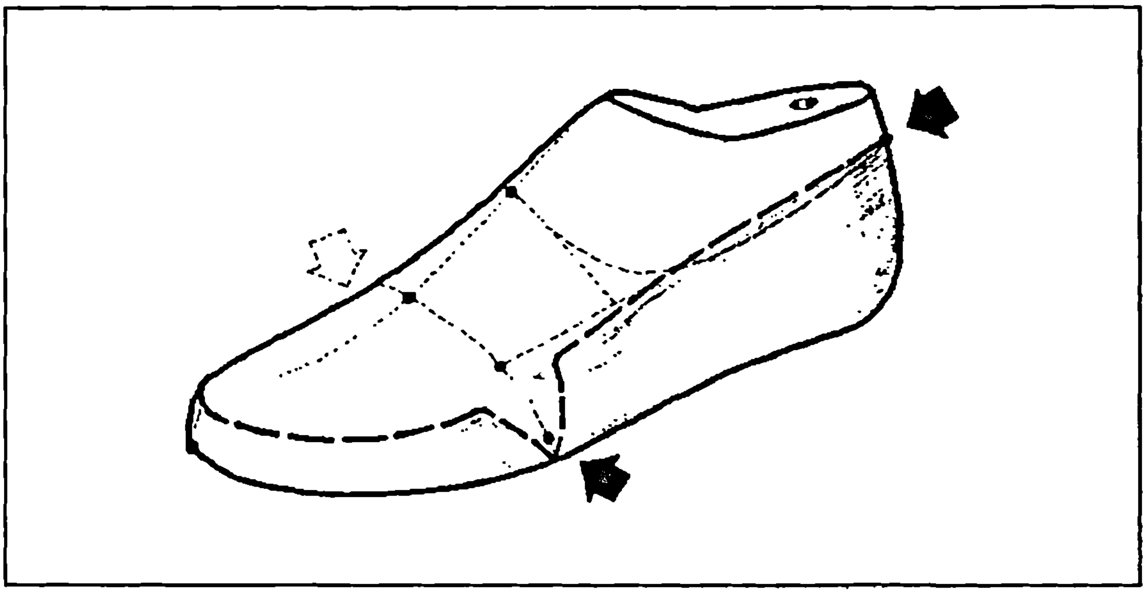

Figure 4.2: BOTTOM CUT WITH WALL AREAS KEPT AND A SPECIAL "V" SHAPED NOTCH ON THE WALL FOR FACILITATE WALKING.

Upper making:

(7) Fix the 2000 micron soft PVC sheet to the frame and heat; (8) Apply SA-23 cement on the surface of the wall of the bottom; (9) Fix the last firmly in the vacuum forming

machine; (10) Press the heated softened PVC sheet downward to cover the last; (11) Turn the vacuum on to shape the upper of the last; (12) Turn the vacuum off; (13) Cut off the upper along the featherline.

Style cutting:

(14) The topline of the shell shoe, and the front opening were determined with reference to style rules observed at Hanssen Orthopaedische Schoentechniek in the Netherlands (see *Chapter 2, Section 2.6*).

Finishing:

(15) Pull the last out of the shell shoe, and remove the insole; (16) Glue the sole units to the shell shoes with SA-23 cement; (17) Place the normal shoe insole into the shell shoe.

4.3.5 Fitting trials

The subject stands on a rigid flat surface, not a carpet which could cause a negative degree in heel pitch height. The subject is then asked to walk leisurely along the walkway, which is about 7.5m to 10m long. A specially designed fitting assessment chart was used to record the fit (see *Appendix IV-IV* for detail).

Since fit assessments are basically subjective, it was decided that only a crude categorisation of response could be used. This allowed five categories:

GOOD FIT (OK)
ADEQUATE BUT ON THE LOOSE/LARGE SIDE (AO+)
ADEQUATE BUT ON THE TIGHT/SMALL SIDE (AO-)
TOO LOOSE/LARGE (UA+)
TOO TIGHT/SMALL (UA-)

The fit of the shoes and the shell shoes is assessed[5] in six areas

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[5] All the fitting assessments were done by the senior shoe-fitter from the Department of Fitting service of C&J Clarks Ltd.

(1) FOREPART:

Toe spring: Measure the toe spring of the shoe and compare it with the standard[6] or the original last. This item is usually used to check the pairing of the shoes after pulling them out of their lasts, before they are worn.

Effective foot length: Press the room in front of the toes (especially the longest toe) and check that it complies with the standard[7]. This is an important factor which must be well dealt with at the last designing stage and checked during the fit assessment. If necessary, cut a "window" at the toe cap of the shoe with the shoe off the foot.

Forepart fit (width): Find the ball joint positions with the fingers and check the width of the shoe at the forepart and compare with the width between foot and shoe, especially at the widest part of the ball joint area. Then make sure that the fit (width) of the foot in the forepart is correct without excessive pressure or fullness.

Alignment: Make sure that the foot shape is aligned correctly in the forepart of the shoe and there is no excessive pressure on the big toe, the longest toe and the smallest toe.

Forepart depth: Is there sufficient depth for all the toes or is there excessive depth anywhere? Squeeze the vamp area of the shoe across the joints inward from the medial and lateral side walls. If there are too many creases at the vamp of the upper, the forepart is too deep. This item is usually assessed together with forepart width.

(2) WAIST:

Waist fit: Is there any excessive space in the inner (medial) or outer (lateral) waist? Assess the fit of the waist with fingers checking the arch area.

Heel to ball: Does the joint of the metatarsal-heads (ball) of the foot coincide with the ball of the shoe? Find the ball joint positions with the fingers and make sure the medial and lateral ball joints are located at the widest part of the shoe. Take a heel to ball measurement if necessary.

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[6] The higher the heel, the less toe spring is required, Mr. A. Weston, senior expert in model last designer and maker of Mobbs Miller Ltd., pointed out that most of the model last designers and makers have been simplifying the toe spring from varying flexibility to a single value of 8 mm (about the diameter of a pencil).

[7] The room in the front of the shoe should be able to accommodate the toe of the foot with an extra space for movement and styling needed for adults; in the case of a child, a growth allowance is also required (Clarks recommends that the toe room allowance for child is about (1/2 inch).

(3) INSTEP:

Balance of throat/quarters: Does the shoe appear to be balanced in the instep area or are the depths of the inner and outer quarters incorrect due to poorly designed patterns or incorrect shoemaking?

Instep fit: Is the fit around the instep good? If a lace bar or gusset style is being assessed. Are the bars or facings positioned correctly? Is the facing gap even?

Fastening: Make sure that there are enough eyelets (or D-rings) for stretching and the velcro must be effective. Record the facing gap[8] or buckle position on the bar and check it with the original design.

(4) QUARTERS:

Topline gap/appearance: Is there any gap on the toplines and does the appearance look satisfactory? Feel with fingers along the topline to make sure the topline fits neatly against the foot.

Under ankle height: Is there any pressure on the ankle bones, or is the topline almost touching the ankle bones (especial the lateral ankle bone)? The ankle bone must be clear of the topline, although this may not be necessary if the topline is padded.

(5) BACKPART:

Seat (width) fit: Is the seat (width) fit correct? If necessary, cut "windows" in both sides of the shoes with shoe off the foot. Is the foot positioned squarely in seat area?

Heel pitch: Is the heel pitching correctly?

Heel curve: Is there excessive pressure at the top of the back curve, or is there obvious gaping? Is the foot in contact with the back curve? Cut a "window" if necessary.

Heel grip: Is there excessive grip or does the shoe slip as the subject walks? Ask the subject to sit down, and pull firmly to ensure no heel slip.

This results were taken from subjects' (subjective) feeling.

(6) WALKING:

When the subject is walking, check for topline gaping. Also, make sure the subject does walk well and there is no heel slip.

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[8] Clarks recommends that there must be a minimum facing gap of 6mm (1/4 inch) for Oxford (Gibson) styles.

4.4 Results and analysis

Table 4.2 shows the results of the intra-observer test. Measures were taken by observer (RC) on the same subject (5D08) at different times of the day (11:00, 12:00 and 22:00). The column *RIGHT.D(max-min)* records the differences between the biggest and the smallest measures which were taken from the right foot and the *LEFT.D(max-min)* lists the differences of those taken from the left foot.

SUBJECTS NUMBER		5D08	
ITEMS / FOOT	AVERAGE (%)	**RIGHT.D(max-min)**	**LEFT.D(max-min)**
Foot (Stick) Length	2.0 (0.8%)	2	2
Medial Heel to Ball	1.5 (0.8%)	1	2
Medial Heel to Ankle	1.5 (2.7%)	1	2
Heel to Smallest toe	3.0 (1.5%)	2	4
Lateral Heel to Ball	1.5 (0.9%)	1	2
Lateral Heel to Ankle	2.5 (5.7%)	2	3
AVERAGE (LENGTH)	**2.0 (2.5%)**	**1.50**	**2.50**
Joint Girth	2.0 (0.9%)	3	1
Waist Girth	3.0 (1.4%)	3	3
Instep Girth	6.0 (2.6%)	6	6
Long Heel Girth	0	0	0
Short Heel Girth	2.5 (0.8%)	2	3
Medial Malleoli Girth	3.0 (1.4%)	4	2
AVERAGE (GIRTH)	**2.75(1.2%)**	**3.00**	**2.50**
Big Toe Height	1.5 (8.8%)	2	1
1st Metatarsal-head Height	1.5 (4.8%)	2	1
5th Metatarsal-head Height	0	0	0
Instep Height	2 (4.0%)	2	2
Short Heel Height	0.5 (0.7%)	0	1
Medial Malleoli Height	2.5 (3.4%)	2	3
Lateral Malleoli Height	1.5 (2.3%)	1	2
AVERAGE (HEIGHT)	**1.36(3.4%)**	**1.29**	**1.43**
TOTAL AVERAGE	**2.03(2.4%)**	**1.93**	**2.14**

Table 4.2: RESULTS OF INTRA-OBSERVER TESTS SHOWING DISCREPANCY IN MEASURES. (unit: mm)

Table 4.3 presents the results of inter-observer tests used to check the degree (absolute value) of differences, *d(RC-JT)*, between two operators (**JT** and **RC**) who took the measures on the same subject (5D07). Before the measurements were taken, some points were determined and marked on the subjects' feet to get the same references.

SUBJECT	5D07(RC)	5D07(JT)	d(RC-JT)	
ITEMS/FOOT	RIGHT (LEFT)	RIGHT (LEFT)	RIGHT	LEFT
Foot (Stick) Length	235 (233)	234 (232)	1	1
Medial Heel to Ball	174 (174)	173 (175)	1	1
Medial Heel to Ankle	50 (52)	53 (53)	3	1
Heel to Smallest toe	195 (197)	193 (193)	2	4
Lateral Heel to Ball	158 (158)	159 (160)	1	2
Lateral Heel to Ankle	47 (49)	50 (51)	3	2
AVERAGE (LENGTH)			**1.8**	
Joint Girth	227 (228)	227 (227)	0	1
Waist Girth	224 (224)	220 (220)	4	4
Instep Girth	232 (234)	228 (230)	4	4
Long Heel Girth	353 (352)	345 (342)	8	10
Short Heel Girth	309 (308)	310 (307)	1	1
Medial Malleoli Girth	230 (237)	232 (234)	2	3
AVERAGE (GIRTH)			**3.5**	
Big Toe Height	21 (23)	20 (20)	1	3
1st Metatarsal-head Height	35 (34)	33 (34)	2	0
5th Metatarsal-head Height	22 (23)	21 (21)	1	2
Instep Height	60 (58)	57 (55)	3	3
Short Heel Height	75 (75)	72 (72)	3	3
Medial Malleoli Height	80 (83)	82 (84)	2	1
Lateral Malleoli Height	66 (64)	60 (62)	6	2
AVERAGE (HEIGHT)			**2.3**	
TOTAL AVERAGE			**2.5**	

Table 4.3: THE TEST RESULTS OF INTER-OBSERVER MEASURES.
(TWO OBSERVERS, RC & JT, ON SAME SUBJECT), (unit:mm)

When the girth measures were taken for the first time in the inter-observer test, the differences between the two operators were too great to be acceptable. This was due to using the measuring tape differently and the degree of looseness or tightness applied. It was agreed that the circumferential measurements should be taken using the British Standard method (BS-5943), ie. the measuring tape should be pulled tight enough to compress the tissues a little and then released sufficiently to allow the normal elasticity of the tissues to bring the tape back to correct tension. The results of differences between subjective "**loose**" and "**tight**" measures are shown in **table 4.4**. This task was done by one operator (**RC**) for one subject (5D08) with a **10mm** wide measuring tape.

SUBJECTS	5D08(loose)	5D08(mean)	5D08(tight)	D(loose-tight)	
ITEMS/FOOT	right(left)	right(left)	right(left)	right	left
Foot (Stick) Length	239 (240)	237 (239)	236 (236)	3	4
Medial Heel to Ball	182 (183)	181 (182)	181 (182)	1	1
Medial Heel to Ankle	56 (56)	55 (56)	55 (56)	1	0
Heel to Smallest toe	200 (199)	199 (200)	199 (199)	1	0
Lateral Heel to Ball	158 (158)	158 (158)	158 (158)	0	0
Lateral Heel to Ankle	45 (43)	45 (42)	45 (43)	0	0
AVERAGE (LENGTH)				0.9	
Joint Girth	224 (224)	222 (223)	210 (210)	14	14
Waist Girth	215 (215)	212 (211)	205 (204)	10	11
Instep Girth	231 (233)	230 (230)	220 (217)	11	16
Long Heel Girth	351 (351)	350 (352)	336 (338)	15	13
Short Heel Girth	301 (301)	301 (300)	292 (292)	9	9
Medial Malleoli Girth	220 (219)	214 (214)	211 (207)	9	12
AVERAGE (GIRTH)				11.9	
Big Toe Height	19 (19)	18 (17)	17 (16)	2	3
1st Metatarsal-head Height	32 (32)	31 (31)	28 (29)	4	3
5th Metatarsal-head Height	22 (22)	21 (21)	20 (19)	2	3
Instep Height	50 (51)	48 (50)	46 (47)	4	4
Short Heel Height	69 (69)	66 (68)	65 (66)	4	3
Medial Malleoli Height	74 (75)	73 (73)	73 (74)	1	1
Lateral Malleoli Height	64 (64)	63 (64)	63 (64)	1	0
AVERAGE (HEIGHT)				2.5	
TOTAL AVERAGE				5.1	

Table 4.4: THE TEST RESULTS SHOWING DIFFERENCES BETWEEN LOOSELY AND TIGHTLY.(ONE OBSERVER ON SAME SUBJECT; unit: mm)

A wearing trial was conducted with 18 normal volunteer subjects who were each assessed using both the ordinary shoe and shell shoe methods. Five styles of shoes were selected from the current C&J Clarks' range, of similar design to those used in orthopaedics (eg. low-heeled shoes with fastening over the instep). Both the shoes and their lasts were available from stock. Shell shoes were constructed for each style and size. These shoes use the same sole unit as the ordinary shoes. For reference, all the 18 volunteer subjects' feet were measured by methods similar to those used in the UK orthopaedic trade (BS-5943) and volume shoe manufacturer (Clarks), including length, girth, height measurements and a outline diagram (draft) was drawn.

Table 4.5(A) shows part of a typical completed foot measurement record, (taken from *Appendix IV-V*), listing all the items measured and showing the measures in the right hand columns. **Table 4.5(B)** presents the averages and the ranges of these measurements in both groups of subjects.

Table 4.6 presents the differences, *D(x)=left.x-right.x*, between the left foot and the right foot measurements for the nominal sized 4E and 5D subjects. The negative data indicate that the measures taken from the right foot (*right.x*) are bigger than those from the left foot (*left.x*).

In addition, the averages[9] and ranges of the differences for both 5D and 4E subjects are listed. For example, in the case of the joint girth measurements taken on the 4E subjects, the difference between left and right foot ranges from 0 to 6mm with an average of 2.6mm (8 pairs); in the case of the medial heel to ball measures taken on the 5D subjects, the difference between left and right foot ranges from 0 to 9mm with an average of 3.6mm (10 pairs).

The results of the last measurements are withheld for commercial reasons. However, **table 4.7(A)** to **4.7(D)** show the results of the differences between the last and the foot

[9] The averages and the ranges are taken using the degree of the absolute value.

measures[10], *d(x)=last.x-foot.x*, and referred to hereafter as the last allowances. From the point of view of the measuring positions, only five measurements can be coordinated between the last and foot surface (ie. stick length[11], medial heel to ball length, joint girth, joint width and the seat width). The negative data indicate that the measures of the foot (*foot.x*) are bigger than those of the last (*last.x*). All the results of the differences are listed in *Appendix IV-VI.*

SUBJECTS NUMBER	5D01	5D02	5D03
ITEMS / FOOT	RIGHT(LEFT)	RIGHT(LEFT)	RIGHT(LEFT)
Foot (Stick) Length	239 (236)	239 (237)	235 (239)
Medial Heel to Ball	177 (178)	176 (177)	171 (178)
Medial Heel to Ankle	56 (53)	54 (48)	47 (50)
Heel to Smallest toe	192 (193)	200 (204)	195 (196)
Lateral Heel to Ball	155 (156)	167 (161)	149 (150)
Lateral Heel to Ankle	50 (47)	46 (47)	40 (41)
Joint Girth	229 (232)	225 (228)	230 (235)
Waist Girth	224 (227)	217 (222)	221 (227)
Instep Girth	232 (233)	229 (232)	234 (235)
Long Heel Girth	352 (355)	354 (349)	345 (343)
Short Heel Girth	307 (305)	315 (312)	302 (305)
Medial Malleoli Girth	234 (237)	237 (235)	229 (230)
Big Toe Height	17 (17)	19 (19)	20 (19)
1st Metatarsal-head Height	32 (33)	37 (37)	38 (36)
5th Metatarsal-head Height	23 (21)	25 (23)	21 (22)
Instep Height	57 (57)	56 (56)	61 (59)
Short Heel Height	79 (77)	78 (77)	80 (74)
Medial Malleoli Height	85 (83)	83 (84)	91 (83)
Lateral Malleoli Height	79 (76)	73 (72)	73 (72)
Joint Width*	93 (96)	88 (88)	94 (94)
Seat Width	58 (57)	58 (57)	54 (54)
*Difference(weight-on/off)	10 (11)	11 (11)	12 (11)

Table 4.5(A): PARTIAL RESULTS OF SUBJECTS' FEET MEASUREMENT.
(unit: mm)

[10] These are the differences between the last and the right foot measures; the differences between the last and the left foot are shown in parenthesis.

[11] The abbreviations are: Stick length= d(SL), Medial heel to ball= d(MHB), joint girth= d(JG), joint (tread-line) width= d(JW), and seat width= d(SW).

Numbers of subjects	4E SUBJECTS: 8		5D SUBJECTS: 10	
ITEMS/FOOT	Average	Range	Average	Range
Foot (Stick) Length	227.6	220 - 233	237.6	233 - 242
Medial Heel to Ball	168.9	165 - 173	177.8	171 - 189
Medial Heel to Ankle	48.6	42 - 53	51.5	47 - 56
Heel to Smallest toe	188.3	180 - 198	198.6	192 - 204
Lateral Heel to Ball	148.2	137 - 158	157.0	149 - 167
Lateral Heel to Ankle	38.9	36 - 44	43.0	35 - 50
Joint Girth	226.8	219 - 239	229.9	221 - 238
Waist Girth	207.6	211 - 227	222.1	212 - 228
Instep Girth	230.0	221 - 242	233.7	228 - 237
Long Heel Girth	336.3	323 - 352	350.7	339 - 359
Short Heel Girth	302.0	285 - 317	309.3	300 - 320
Medial Malleoli Girth	227.3	215 - 240	231.1	213 - 239
Big Toe Height	19.8	17 - 24	19.8	15 - 23
1st Metatarsal-head Height	35.8	32 - 37	35.4	30 - 38
5th Metatarsal-head Height	23.9	21 - 28	23.7	21 - 27
Instep Height	56.6	50 - 62	57.6	49 - 64
Short Heel Height	76.6	71 - 84	77.8	66 - 88
Medial Malleoli Height	79.0	75 - 84	82.9	74 - 91
Lateral Malleoli Height	70.3	64 - 76	71.8	64 - 79
Joint Width*	89.9	86 - 96	91.3	86 - 94
Seat Width	57.4	54 - 63	58.5	54 - 63
*Difference(weight-on/off)	8.6	6 - 13	9.9	6 - 13

Table 4.5(B): THE AVERAGES & RANGES OF THE SUBJECTS' FEET MEASUREMENT. (unit: mm)

4E Subjects	mean	range	01	02	03	04	05	06	07	08
foot (stick) length	1.8	0 - 3	0	-2	-3	-1	3	-3	-1	1
medial heel to ball	2.6	0 - 5	4	-1	-3	0	5	-5	3	0
medial heel to ankle	2.6	1 - 7	-1	2	-7	-1	-2	3	2	3
heel to smallest toe	2.9	0 -10	1	-5	1	0	1	10	-1	4
lateral heel to ball	2.5	0 - 5	1	-4	-3	3	2	-2	-5	0
lateral heel to ankle	2.0	0 - 7	0	3	-7	0	-2	2	1	1
joint girth	2.6	0 - 6	-1	-1	2	3	0	-5	6	3
waist girth	1.6	0 - 3	-1	0	3	2	3	1	2	-1
instep girth	2.8	1 - 4	-3	3	-4	-1	3	-3	2	3
long heel girth	2.0	1 - 5	-2	5	-1	-3	-2	-1	1	1
short heel girth	2.0	0 - 4	-1	0	-4	4	4	-1	-1	1
medial malleoli girth	3.6	1 - 6	3	5	-5	4	-2	6	3	1
big toe height	1.8	0 - 4	-2	1	4	-1	3	0	1	-2
1st metatarsal-head height	2.6	0 -12	-2	3	2	0	2	1	2	0
5th metatarsal-head height	1.1	0 - 3	0	-1	1	-1	-1	0	2	-3
instep height	2.4	1 - 5	-3	5	3	2	-1	-1	2	2
short heel height	2.9	0 - 6	-3	-3	4	0	-2	-6	-1	4
medial malleoli height	2.8	0 - 6	-4	0	6	1	-4	-1	4	-2
lateral malleoli height	2.5	0 - 4	2	-3	-3	2	-3	-3	0	4
joint width	1.4	0 - 4	1	-1	-1	2	1	0	1	-4
seat width	0.8	0 - 1	-1	-1	1	-1	1	1	0	0

5D Subjects	mean	range	01	02	03	04	05	06	07	08	09	10
foot (stick) length	2.3	1 - 4	-3	-2	4	-2	2	1	-2	2	3	2
medial heel to ball	3.6	0 - 9	1	1	7	6	5	9	0	0	6	2
medial heel to ankle	3.1	1 - 6	-3	-6	3	-1	-4	4	2	-1	-3	-4
heel to smallest toe	1.6	0 - 4	1	4	1	1	1	0	2	2	1	3
lateral heel to ball	1.4	0 - 6	1	-6	1	1	-4	0	0	1	0	0
lateral heel to ankle	1.6	0 - 4	-3	1	1	0	1	1	2	-1	4	2
joint girth	1.9	0 - 5	3	3	5	-2	-1	-1	1	1	0	-2
waist girth	2.7	0 - 6	3	5	6	-1	6	-1	0	1	1	-3
instep girth	1.8	0 - 5	1	3	1	1	0	-5	2	3	-1	-1
long heel girth	2.8	1 - 5	3	-5	-2	5	-5	-1	-1	2	-2	-2
short heel girth	2.6	1 - 6	-2	-3	3	2	1	5	-1	-2	6	1
medial malleoli girth	2.4	0 - 7	3	-2	1	1	0	2	7	-1	4	-3
big toe height	1.1	0 - 4	0	0	-1	-1	1	1	3	0	0	4
1st metatarsal-head height	1.2	0 - 3	1	0	-2	-3	2	0	-1	2	-1	0
5th metatarsal-head height	1.4	0 - 3	-2	-2	1	1	3	1	1	0	2	1
instep height	1.7	0 - 4	0	0	-2	1	-4	1	-2	2	3	-2
short heel height	2.3	0 - 6	-2	-1	-6	-2	-3	0	0	2	-4	-3
medial malleoli height	2.2	0 - 8	-2	1	-8	3	1	1	3	1	0	2
lateral malleoli height	2.2	1 - 4	-3	-1	-1	-2	4	-2	-2	-1	-4	2
joint width	1.1	0 - 3	3	0	0	-1	-1	0	-1	-2	0	-3
seat width	0.8	0 - 2	-1	-1	0	-1	0	-2	0	2	-1	0

Table 4.6: THE DIFFERENCES BETWEEN THE LEFT & THE RIGHT FOOT MEASURES OF 4E & 5D SUBJECTS (unit: mm).

8676D	d(SL)	d(MHB)	d(JG)	d(JW)	d(SW)
4E01	20 (20)	-3 (-7)	-16 (-15)	-11 (-12)	-2 (-1)
4E02	14 (16)	-8 (-7)	-11 (-10)	-9 (-8)	0 (1)
4E03	21 (24)	-10 (-7)	-22 (-24)	-16 (-15)	-3 (-4)
4E04	26 (27)	-2 (-2)	-9 (-12)	-9 (-11)	0 (1)
4E05	20 (17)	-2 (-7)	-8 (-8)	-10 (-11)	-2 (-3)
4E06	20 (23)	-6 (-1)	-16 (-11)	-10 (-10)	-2 (-3)
4E07	16 (17)	-6 (-9)	-16 (-22)	-13 (-14)	-2 (-2)
4E08	15 (14)	-9 (-9)	-28 (-25)	-18 (-14)	-5 (-5)
AVERAGE	19.4	-5.9	-15.8	-11.9	-1.6

Table 4.7(A): DIFFERENCES BETWEEN LAST-8676D & FOOT OF 4E (unit:mm).

8933	d(SL)	d(MHB)	d(JG)	d(JW)	d(SW)
5D01	15 (18)	-12 (-13)	-2 (-5)	-6 (-9)	6 (7)
5D02	15 (17)	-11 (-12)	2 (-1)	-1 (-1)	6 (7)
5D03	19 (15)	-6 (-13)	-3 (-8)	-7 (-7)	10 (10)
5D04	15 (17)	-7 (-13)	-11 (-9)	-7 (-6)	7 (8)
5D05	16 (14)	-11 (-16)	-6 (-5)	-7 (-6)	3 (3)
5D06	13 (12)	-15 (-24)	-6 (-5)	-3 (-3)	1 (3)
5D07	19 (21)	-9 (-9)	0 (-1)	-5 (-4)	4 (4)
5D08	18 (16)	-16 (-16)	6 (5)	-3 (-1)	9 (7)
5D09	18 (15)	-10 (-16)	-6 (-6)	-4 (-4)	1 (2)
5D10	19 (17)	-12 (-14)	1 (3)	-2 (1)	6 (6)
AVERAGE	16.5	-12.8	-2.6	-3.4	4.9

Table 4.7(B): DIFFERENCES BETWEEN LAST-8933 & FOOT OF 5D (unit:mm).

9036/2	d(SL)	d(MHB)	d(JG)	d(JW)	d(SW)
5D01	15 (18)	-8 (-9)	-3 (-6)	-8 (-11)	1 (2)
5D02	15 (17)	-7 (-8)	1 (-2)	-3 (-3)	1 (2)
5D03	19 (15)	-2 (-9)	-4 (-9)	-9 (-9)	5 (5)
5D04	15 (17)	-3 (-9)	-12 (-10)	-9 (-8)	2 (3)
5D05	16 (14)	-7 (-12)	-7 (-6)	-9 (-8)	-2 (-2)
5D06	13 (12)	-11 (-20)	-7 (-6)	-5 (-5)	-4 (-2)
5D07	19 (21)	-5 (-5)	-1 (-2)	-7 (-6)	-1 (-1)
5D08	18 (16)	-12 (-12)	5 (4)	-5 (-3)	4 (2)
5D09	18 (15)	-6 (-12)	-7 (-7)	-6 (-6)	-4 (-3)
5D10	19 (17)	-8 (-10)	0 (2)	-4 (-1)	1 (1)
AVERAGE	**16.5**	**-8.8**	**-3.2**	**4.9**	**0.1**

Table 4.7(C): DIFFERENCES BETWEEN LAST-9036/2 & FOOT OF 5D (unit:mm).

8892	d(SL)	d(MHB)	d(JG)	d(JW)	d(SW)
5D01	13 (16)	-12 (-13)	1 (-2)	-13 (-16)	1 (2)
5D02	13 (15)	-11 (-12)	5 (2)	-8 (-8)	1 (2)
5D03	17 (13)	-6 (-13)	0 (-5)	-14 (-14)	5 (5)
5D04	13 (15)	-7 (-13)	-8 (-6)	-14 (-13)	2 (3)
5D05	14 (12)	-11 (-16)	-3 (-2)	-14 (-13)	-2 (-2)
5D06	11 (10)	-15 (-24)	-3 (-2)	-10 (-10)	-4 (-2)
5D07	17 (19)	-9 (-9)	3 (2)	-12 (-11)	-1 (-1)
5D08	16 (14)	-16 (-16)	9 (8)	-10 (-8)	4 (2)
5D09	16 (13)	-10 (-16)	-3 (-3)	-11 (-11)	-4 (-3)
5D10	17 (15)	-12 (-14)	4 (6)	-9 (-6)	1 (1)
AVERAGE	**14.5**	**-12.3**	**0.2**	**-11.3**	**0.1**

Table 4.7(D): DIFFERENCES BETWEEN LAST-8892 & FOOT OF 5D (unit:mm).

Table 4.8 shows an example of a completed fit assessment form designed for this trial which lists the results of ONE feature for all subjects (taken from *Appendix IV-VII*: forepart fit 3.1/14, 3.2/14). The fit of the ordinary shoes was assessed by experienced shoe-fitters according to a procedure normally used in such in-house fitting trials at volume shoe manufacturer (C&J Clarks). An appropriate procedure for shell shoes fitting was defined, based on the methods observed in use by the Dutch orthopaedic shoe companies.

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES		*			
		SHELLS		*			
4E02	POP-LIFE	SHOES		*			
		SHELLS		*			
4E03	POP-LIFE	SHOES	*				
		SHELLS	*				
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES		*			
		SHELLS		*			
4E07	POP-LIFE	SHOES		*			
		SHELLS		*			
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES		*			
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	

Table 4.8 (continued next page)

Table 4.8 (continued)

5D04	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D05	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	

Table 4.8: EXAMPLE OF DETAILED CHART FOR FOREPART FIT ASSESSMENT.

Table 4.9 is a summary of the fitting results for all features taken from assessing 4 pairs of stock shoes and 4 pairs of shell shoes on 18 volunteer subjects.

FEATURE	TYPES	NUMBERS OF ASSESSMENTS: 35 [12]				
		UA-	AO-	OK	AO+	UA+
TOE SPRING	SHOES	-	-	35	-	-
	SHELLS	-	-	35	-	-
EFFECTIVE LENGTH	SHOES	2	2	26	4	1
	SHELLS	2	1	27	4	1
FOREPART FIT	SHOES	2	12	16	5	-
	SHELLS	2	11	17	5	-
ALIGNMENT [13]	SHOES	-	-	29	-	-
	SHELLS	-	-	29	-	-
FOREPART DEPTH	SHOES	3	8	16	8	-
	SHELLS	3	8	16	8	-
WAIST FIT	SHOES	1	6	25	3	-
	SHELLS	1	5	26	3	-
HEEL TO BALL	SHOES	1	6	28	-	-
	SHELLS	1	6	28	-	-
INSTEP FIT	SHOES	3	8	21	3	-
	SHELLS	3	7	22	3.	-
TOPLINE	SHOES	1	2	30	2	-
	SHELLS	1	2	30	2	-
UNDER ANKLE HEIGHT	SHOES	-	-	35	-	-
	SHELLS	-	-	35	-	-
SEAT WIDTH	SHOES	-	5	30	-	-
	SHELLS	-	5	30	-	-
HEEL PITCH	SHOES	-	-	35	-	-
	SHELLS	-	-	35	-	-
HEEL CURVE	SHOES	-	1	32	2	-
	SHELLS	-	1	28	4	2
HEEL GRIP	SHOES	-	3	30	2	-
	SHELLS	-	1	10	20	4

Table 4.9: SUMMARY OF FITTING ASSESSMENT FOR ALL FEATURES.

[12] The number of fit assessments is 35. 8 (4E) subjects trialled one single style (Pop-life), and 10 (5D) subjects each trialled three styles (Nocturne, Ohio and 2nd Nature) with the exception of 3 subjects for whom the Ohio style was not available (see table 4.1 for detail).

[13] Not possible to assess these features in 6 (out of 35) cases, where the foot is too wide.

Table 4.10 shows the results of the comparison between the standard shoe fitting and the shell shoe fitting for **all** 14 features checked.

FEATURES (number)	SHOES=SHELLS	SHOES<>SHELLS
TOE SPRING (35)	35 (100%)	0
EFFECTIVE LENGTH (35)	34 (97.1%)	1
FOREPART FIT (35)	34 (97.1%)	1
ALIGNMENT (29)	29 (100%)	0
FOREPART DEPTH (35)	35 (100%)	0
WAIST FIT (35)	34 (97.1%)	1
HEEL TO BALL (35)	35 (100%)	0
INSTEP FIT (35)	34 (97.1%)	1
TOPLINE (35)	35 (100%)	0
UNDER ANKLE HEIGHT (35)	35 (100%)	0
SEAT WIDTH (35)	35 (100%)	0
HEEL PITCH (35)	35 (100%)	0
HEEL CURVE (35)	29 (82.9%)	6
HEEL GRIP (35)	10 (28.6%)	25
TOTAL (484)	449 (92.8%)	35 (7.2%)

Table 4.10: COMPARISON BETWEEN THE TWO DIFFERENT FITTING ASSESSMENT METHODS.

4.5 Discussion

Although the majority of shoes were good fits, fortuitously some were used which were too small/tight or too large/loose (see **table 4.9**). This allowed for an assessment of the shell shoe technique's ability to detect these misfits, and an assessment of the last allowances tolerances for a good fit.

4.5.1 Comparison of measurements

Joint girth measurements:

Measured on the 5D subjects (see **table 4.6(B)**), the difference between left and right foot of the same subject ranges from 0 to 5mm, average 1.9mm (10 pairs). The range of joint girths of the foot was 17mm (20 feet). The equivalent range on the lasts was 4mm (3 styles). The average joint girth of the feet was 2.1mm greater than that of the lasts. For individual feet compared with the last of each shoe worn, the differences ranged from 9mm smaller to 12mm bigger, a total variation of 21mm (over three width fittings).

Measured on the 4E subjects (see **table 4.6(A)**), the differences between left and right foot of the same subject ranges from 0 to 6mm, average 2.6mm (8 pairs). The range of joint girth on the 4E subjects was 20mm (16 feet). Only one style was used and the average joint girth of the feet was 15.8mm greater than the girth of the matching last. For individual feet, the difference ranged from 8mm to 28mm bigger.

Clearly there is a discrepancy in the joint girth allowances between the 5D set (average 2.1mm) and the 4E set (15.8mm). To make sense of this, it is necessary to refer to the forepart fit 3.1 & 3.2 and the forepart depth 5.1 & 5.2 (see *Appendix IV-VII*). In the case of 5D subjects, the forepart fit and depth was felt to be acceptable for all subjects in all 3 styles (see **figure 4.3**: diagram A to C).

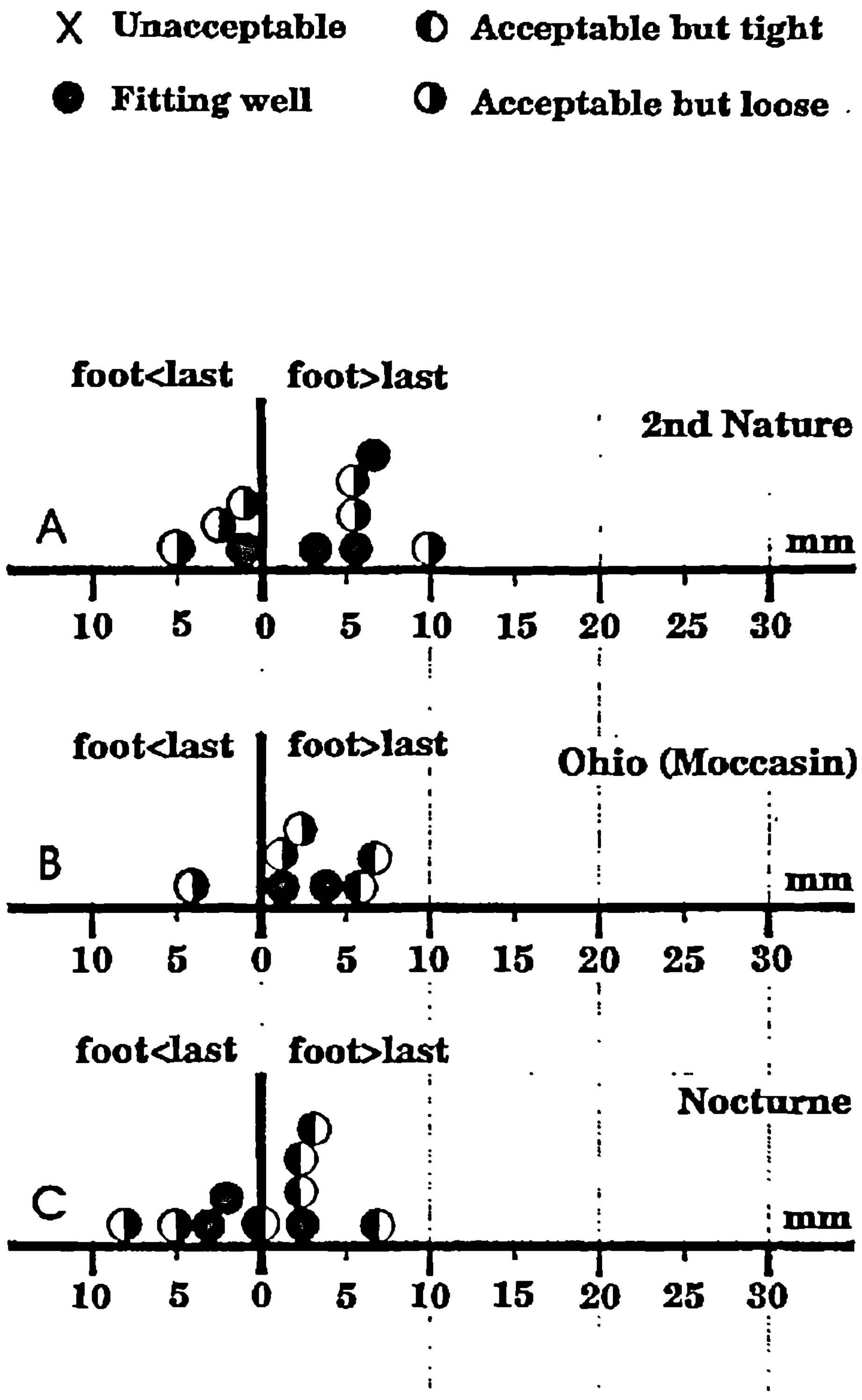

Figure 4.3: FOREFOOT FIT vs. LAST ALLOWANCES FOR THE SIZE 5D SUBJECTS.(A:2nd NATURE, B:OHIO, C:NOCTURNE)

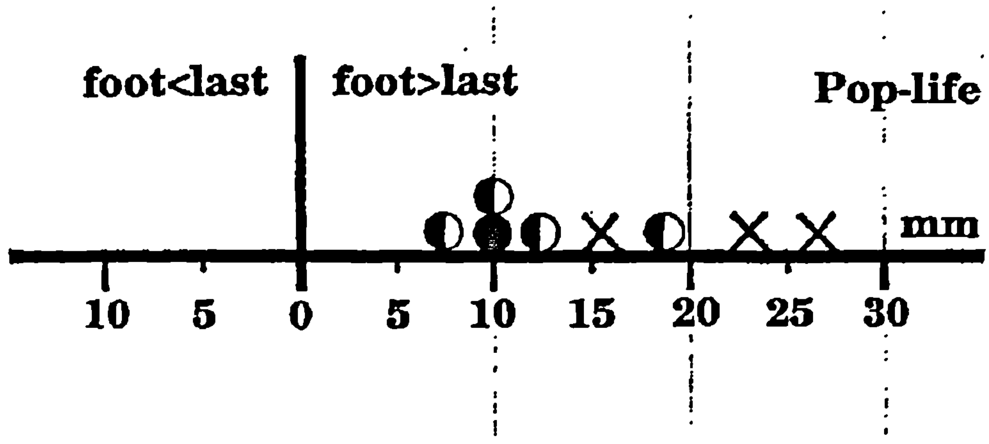

Figure 4.4: FOREFOOT FIT vs. LAST ALLOWANCES FOR THE SIZE 4E SUBJECTS. (POP-LIFE STYLE)

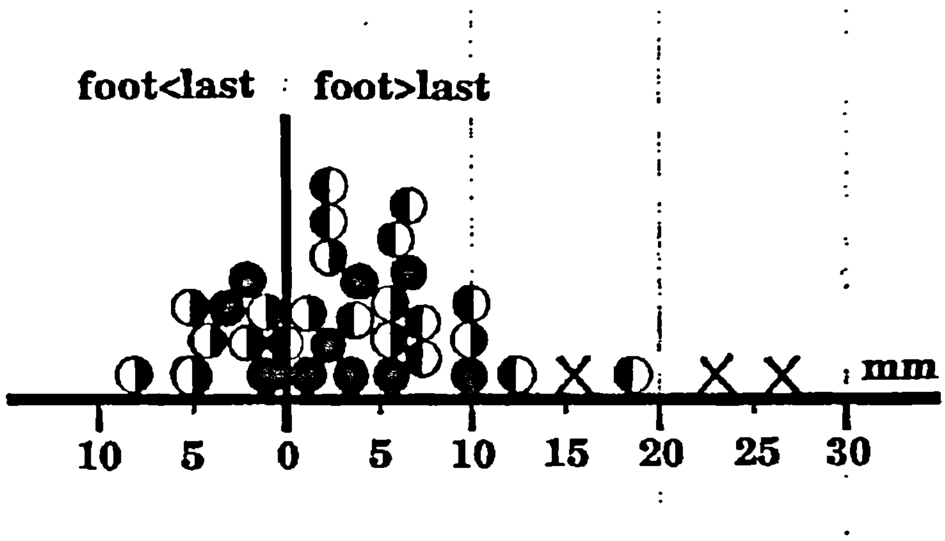

Figure 4.5: FOREFOOT FIT vs. LAST ALLOWANCES FOR ALL SUBJECTS IN ALL STYLES.

Whereas for 7/8 of the 4E subjects, the fit assessments showed that the shoe was too tight, and three of them were unacceptably tight (**figure 4.4**). In forepart width assessment, four were found to be acceptable but tight, and a further two were unacceptably tight. In forepart depth assessment, four were found to be acceptable but not deep enough, and a further three unacceptably shallow. This indicates that in the case of 5D subjects, a girth difference between foot and lasts of approximately 2mm is acceptable on average, whereas in the case of 4E subjects, the difference of approximately 16mm produces some fit problems. Even such a big difference, however, is not always indicative of poor fit, since the ranges within which fit is acceptable are wide ie. 9mm smaller to 12mm bigger (see **figure 4.5**).

These results are interesting but not extensive enough to be a definitive statement on last allowances. A further trial of a specific nature is indicated, where the degree of misfit is controlled to give a clearer definition of the boundaries between "OK", "AO-/+", and "UA-/+" categories; additionally more subject-related factors should be recorded to indicate the origin of the spread of last allowances.

Foot and last length:

Based on effective length, both shells and shoes are too long for subject 4E04; and too short for subject 5D06. Except for these two mis-fit cases, the stick length of the shoes (or lasts) is about 16.8mm on average longer than the effective foot length of the right foot and 16.5mm longer for the left. There is a range of between 12mm to 23mm, which is about 2 sizes (within 1 $^1/_2$ - 2 $^1/_2$ sizes) longer than the foot length. It is valued as fore-part allowance for designing the forepart styles of the shoes.

Heel to ball length (medial):

Measured on the 5D subjects, the difference between left and right foot of the same subject ranges from 0 to 9mm, average 3.7mm (10 pairs). The range of medial heel to ball length of the foot was 18mm (20 feet). The equivalent range on the lasts was 4mm (3 styles). The average medial heel to ball length of the feet was 11.4mm longer than that of the lasts. For the individual feet compared to the last of each shoe worn, the differences ranged from 2mm to 24mm longer, a total variation of 22mm (over 2 $^1/_2$ sizes).

Measured on the 4E subjects, the difference between left and right foot of the same subject ranges from 0 to 5mm, average 2.6mm (8 pairs). The range of medial heel to ball lengths of the foot was 9mm (16 feet). Only one style was used, and the average medial heel to ball length of the feet was 5.9mm longer than that of the matching last. For individual feet, the difference ranged from 1mm to 10mm. According to these measures, it should have caused serious misfit problems in heel to ball assessment. However, only one 4E subject found it unacceptably short, 2/8 subjects found it slightly shorter but acceptable in 4E style. For the 5D subjects, in all case, it was felt to be *OK* or acceptable in all 3 styles.

Although most of the 4E and 5D subjects found the heel to ball fit *OK* or acceptable, there is an anomaly which requires explanation. Subject-4E08 found the heel to ball measure of 9 mm longer than the matching last unacceptable, whereas in the case of 20 other measures, there were difference of 9 mm or longer and yet there was a good fit (see **table 4.7**). The answer can be found by comparing the heel to ball and joint girth measurements. The differences of those 20 measures in joint girth ranged from 9mm bigger to 11mm smaller, which is at least 14mm greater than that of subject 4E08. This gives enough room for the foot to move forward in the shoe. When heel to ball length of the foot is longer than that of the last, it is necessary to give extra space to accommodate the joint of the foot which is forward of the shoe joint position. Obviously, this indicates that fitting assessment at the heel to ball region could sometimes be affected by joint girth. This is an important check point in forepart fit assessment.

4.5.2 Comparison of fitting assessment

Back heel grip:

From the results of the assessment fitting in **table 4.10**, it is seen that 8 of the 14 check-points are 100% the same and in total 92.8% compared results are the identical between standard and shell shoe fitting assessment. Only one assessed feature was not useful i.e. heel grip, which is caused by different pattern engineering technique, as illustrated in **figure 4.6**. The shell shoe was made by taking the exact shape of the last, whereas in normal shoe making, the pattern designer always cuts about **2-5mm** off from the mean-form at the backseam of the topline, in order to grasp the back heel of the foot. Following the Dutch assessment procedures, a simple cut was taken at the backseam area of the shell shoe to adjust the back heel grip and the back heel curve for the subjects.

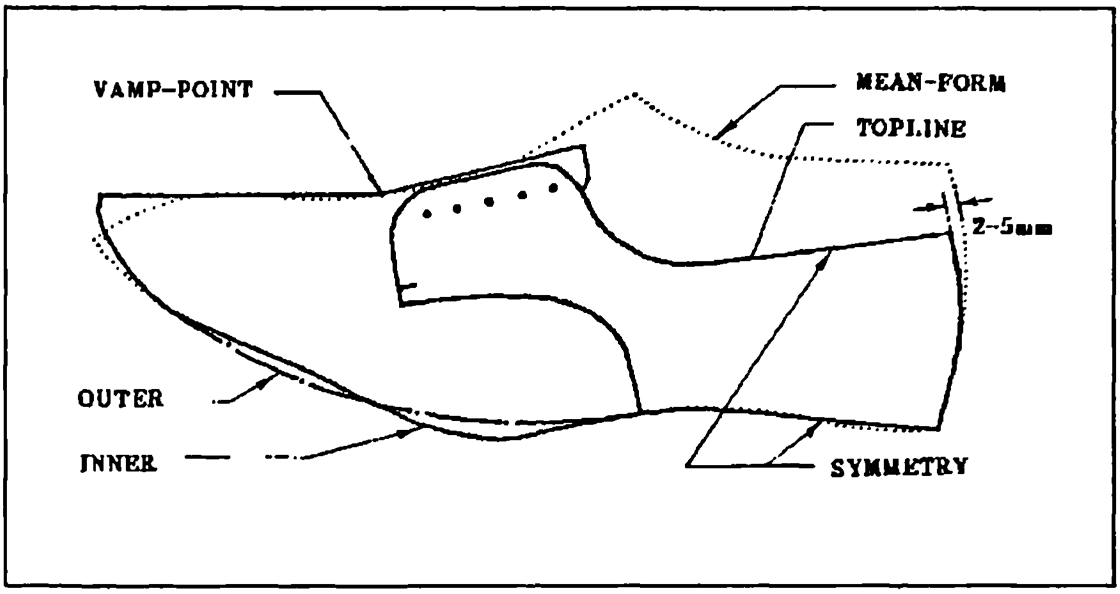

Figure 4.6: 2-5mm SHOULD BE REMOVED FROM MEAN-FORM AT THE BACKSEAM OF TOPLINE IN PATTERNS ENGINEERING.

Outer quarter under ankle height:

It is important that outer (lateral) quarter heights are checked, because if the quarters are too high, the upper topline will cause the under ankle bone discomfort. From the fit assessment results of under ankle height, all shells and shoes were fitted well, even though they were made by different methods. The shells were designed using Dutch style rules with lateral quarter **5mm lower** than medial quarter, whereas the shoes were made as normal with the quarters of both side about the same height, because of the backpart **symmetry** (also see **figure 4.6**). From this point of view, the Dutch (Hanssen) style cutting rules provided a good practice for the pre-style design which allowed under ankle height fitting to be achieved before shoe patterns were made.

Window assessment:

To assist in the fitting assessment for normal shoes, it is sometimes necessary to cut a "**window**" on one shoe of a pair. These windows are always cut in the areas where it is almost impossible to assess the foot in the shoe such as on both sides of the heel, adjacent to the back curve and in front of the big toe, as illustrated in **figure 4.7.** Obviously, because of the transparent material, the shell shoe doesn't need windows cut for fitting assessment.

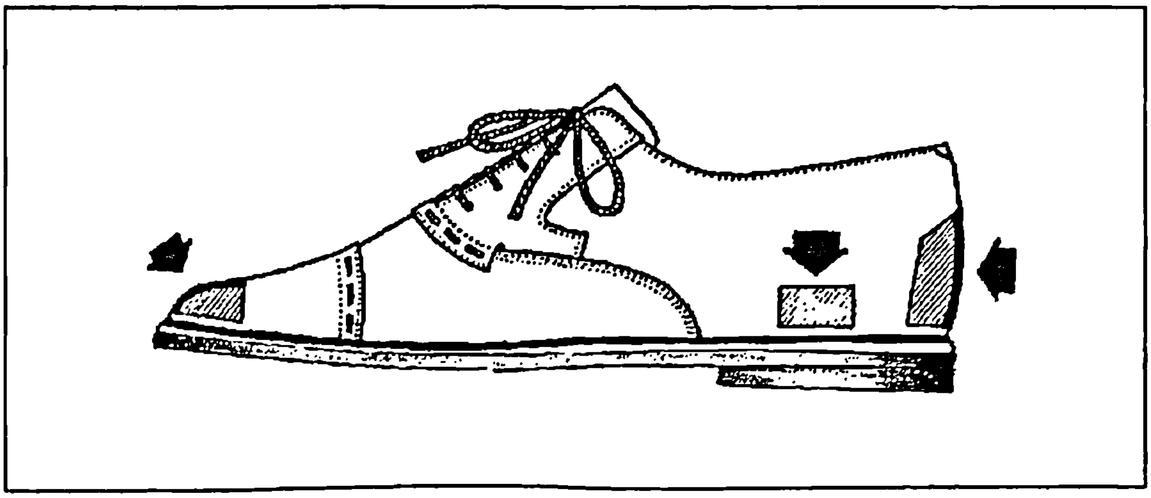

Figure 4.7: SHOE WINDOWED FOR FITTING ASSESSMENT.

Pressure (white patches) on skin:

At the topline point on the mid-line of the forepart cone, the shells show pressure to one side, at the medial (instep) dorsum of the foot. This reflects the fact that the anatomy of the foot is different from the shape of the last. White patches on the skin occurred for almost every subject, where fit was satisfactory in the eyes of both the experienced shoe-fitters and the subjects. It appears that some pressure on the skin is tolerable for the normal foot. We should consider further what level of pressure causes whitening vs. tolerable pressures on tissues. It is also noted that pressure levels tolerated on a normal foot might not be allowed in pathological conditions, especially in the toe area. A patient with diabetic foot problems due to a variable loss of skin sensation will be liable to trauma and may develop trophic ulcers (**Connor et al, 1987**). For the diabetic patient, walking affects the small intrinsic muscles of the feet and gives rise to clawing of the toes, which in turn creates areas of high pressure under the toe tips and uppers. Sometimes shoe pressure may also cause callosities or ulcers over the prominent dorsum of the toes. So, fitting tolerances considered acceptable in normal shoe fitting assessment; might be dangerous and not allowed for orthopaedics. "*My shoes are killing me!*" might be literally true for the orthopaedic patients. It is therefore considered that shells could provide a more efficient and safer method of assessing orthopaedic fittings, especially for patients with sensory loss.

General:

Most of the subjects reported that the shell shoes felt slightly bigger than the standard shoes. This phenomenon might be attributed to any of the following possibilities

- Machine-lasted shoes are always smaller than hand-lasted shoes, because of the shrinkage occurring after the last is pulled out of the shoe; all the assessed shoes were made by machine-lasting methods, and hence they would be slightly smaller than the last.
- The laces of these shoes pulled the topline into a closed circle when tightened firmly. On the other hand, the open topline of the shell shoes, which was cut along the mid-line from topline to vamp point, could have caused the loose feeling; punching eyelets and supplying a lace on the shell shoe affected the subjective reports.
- Different materials caused different sensations to subjects. Although shells are made from soft PVC material, it is not soft enough to mould to the foot closely. In addition the surface of PVC is too smooth to grasp the foot. This may cause some feelings of looseness for the subjects.

Overall, the shell shoe fitting assessment gave a closely similar result to fitting assessment with a standard shoe, except in the heel and topline assessments. Slipping at the heels may be a result of the failure to cut notches in the wall of the shell shoe at the joint position, which inhibits flexing of the shoe during push-off and results in the heel lifting out of the shoe.

4.5.3 Decoupling shape and construction factors

Shoe last shape and shoe construction are the two main factors in fit assessment. Both of them are considered and evaluated together **during** trials. The traditional method of shoe fitting always assesses **after** the sample shoes are made and, at this stage, shoe last shape and its construction have already been selected and decided. Since the trial shoes have been constructed, it is impossible to separate shoe shape from their construction. Therefore, to decouple the two factors of shoe last shape and its construction could allow one to assess fit **before** the shoe was made.

Additionally, if we simplified the construction of shoe making, the upper technique could be ignored as a simple piece of material could be draped on the shoe last only. Whatever the construction of the shoes, all the patterns are cut and assembled from **2D** flattened materials and then shaped on the **3D** shoe last surface, the idea on which the new shell method is based. The results of this trial indicate that the last is the main determinant for fit, since the shell shoes gave the same result as the finished shoes. Construction becomes more of an issue when the shoes are worn, resulting in problems of rubbing etc.

4.6 Conclusions

In this chapter, the methodology of shell shoe fitting has been described in detail. This trial study has indicated that the shell shoe method has the potential to assess the fit in all but a few limited aspects. It has been shown that the shoe last shape is dominant over construction in determining the shoe-related factors. The range of differences between the foot and last measures which were all thought to give a satisfactory fit are outlined, although a further more detailed study is required to define these accurately. The wide range of last allowances could be due to subject-related factors which were not assessed in this trial. Alternatively, these differences could be due to variability in the overall shape of the feet, which can not be defined by taking limited measures.

From the point of view of cost, the orthopaedic shell shoe is cheaper and easier to ship to the fitting service (or clinic). In the case of commercial shoe design, there may also be a saving of cost and time if new lasts are evaluated by the shell shoe method prior to style design. Because the whole study was similar to those used in orthopaedics, the results proved that the shells method can also be used in the orthopaedic field as a more economic and effective technique than is currently used.

CHAPTER 5
DETERMINATION OF LIMITS OF LAST ALLOWANCE

5.1 Introduction

It is obvious that the main purpose of a last is to give a shoe its shape and provide a space to accommodate (or fit) the feet of its expected customers. In the case of bespoke footwear, the purpose above can be achieved easily by testing a pair of shoes which is made on specially fitted-up lasts. The bespoke shoemaker can then modify the lasts as necessary. However, it is impossible for the volume shoe manufacturers to do as the bespoke shoemaker does. The bulk shoe manufacturers require enough information such as statistical models of the averaged feet measurements and the limits of fit tolerance to build up their main fittings in each size. The possibility of improved fitting efficiency applies to ranges which are made currently in accordance with single or multiple fittings. Most shoe manufacturers make footwear only in one fitting in each size. But some well-known manufacturers, particularly those making children's shoes (eg. C&J Clarks and Start-Rite), and high quality men's & ladies' shoes (eg. Barkers, Church and Bally), supply footwear in two, three or four fittings to fit the largest possible segment of the population.

The footwear fittings structures are offered by some manufacturers in a range represented by the letters A to I. In the UK, A is the narrowest fitting of the range. Normally there is a difference of $^1/_4$ inch (about 6.4 mm) between two neighbouring fittings (eg. 5A/5B, 5B/5C, 5C/5D, etc.) in the same size. The **D fitting** usually represents the average women's middle fitting, and **E** (5)[1] represents the men's. For children's, **F** (some manufacturers use E) is very popular. For joint girth (width) grading, there is a $^3/_{16}$ inch (5 mm) interval in joint girth between consecutive sizes up to children's size 10 and $^1/_4$ inch (6.4 mm) above size 10. Based on SATRA's unpublished recommendation, there should be a joint girth of 246.5 mm for an averaged

[1] In the UK, numbers are sometimes used for the men's shoes, eg. **5** is used instead of **E**.

middle fitting men's last (the average foot girth corresponding to this size/fitting is 250 mm), and a joint girth of 214.5 mm for an average-middle fitting women's last (the average foot girth corresponding to this size/fitting is 226 mm).

In chapter 4 where girth measurements taken from individual feet of a group of subjects were compared with the related last of each shoe worn, the differences ranged from 9 mm smaller to 12 mm bigger (total variation of 21 mm). Yet the fitting results of the forepart width and depth were still found acceptable for all subjects in all styles (refer to **figure 4.5**). This indicates that there are probably limits of tolerable last allowances[2], still to be defined. The tolerable last allowances could be defined for all measurements. For what are referred to hereafter as the last allowances, the measurements are mainly in girth regions including joint girth, waist girth, and instep girth; the overall stick length, medial heel to ball length, joint width, and seat width are also measured, both last and feet.

However, the joint (ball) girth measurement is possibly the most important because the metatarsal-phalangeal joints are the most complicated parts in the foot, as their shape changes sharply during standing and walking positions. Also, all major existing sizing/fitting systems (eg. UK/USA and France) are structured and recommended in accordance with the joint measurements. Therefore, the joint girth fitting is chosen as a basis of this study.

In this fitting tolerance experiment, a model last (8892) is selected with size 5 and D fitting, and other model lasts are duplicated and modified from this basic 5D model last with the same size but a range of different girth fittings to nominal sizes (ie. 5B, 5C, 5E, and 5F). In order to keep the shape of the last during the fitting grading, two sets of bottom (insole) patterns, according to the range used in British shoe last trade, are adopted in this trial. Five pairs of special shell shoes are made on these ranged model lasts for fitting assessments, this procedure both reducing costs of making shoes and also obviating difference introduced by pattern design and last tension. By analysing the

[2] Last allowance is a regular interval or difference which is given to or taken from the averaged foot measurements for standard model last design and making.

measurements and fitting results, the limits of the tolerable last fitting allowances can then be identified.

However, these calculated last fitting allowances are only put forward for consideration, not as a tried and proved practical proposition but as something which, like all results of scientific research, must first go through a period of development, testing and modification on a pilot scale. From this point of view, this studied tolerable allowance may provide a useful suggestion for improving the ranges of fitting and result in better fitting for more feet than conventional ranges.

5.2 Aims and objectives

The aims of this study[3] are to identify the limits of tolerable last allowances at girth (particularly in joint) regions.

The objectives of the work presented in this chapter are:

- To assess fit from different graded girth measurements.
- To identify limitation of tolerable fittings on joint girth region of the foot.
- To compare the foot and last measurements and assess the last allowances in other measurements such as heel to ball, joint and seat width.
- To provide recommendations for acceptable ranges of the joint girth allowance for new last designs and manufacturing.

[3] This study is associated with EUREKA PROJECT "SELECT".

5.3 Trial protocol

In this experiment, a number of techniques are required i.e. foot measurement, shell shoe making and style cutting, fit assessment skills, last assessment, last duplicating with different (ranged) measures in bottom pattern, joint girth, waist girth, instep girth and seat region. Five different girth fittings of the same notional lasts (ie. B, C, D, E, F fittings) were developed according to a special grading order (ie. forepart and backpart are graded as required). Then these were trialled on a number of normal subjects of this notional shoe size (ie. size 5). As general background information was required, all the feet and lasts were measured extensively. The shell shoe fitting has been proved as a useful method to assess the fit. In this trial, the shells are adopted again.

The stages in this trial can be identified as:

- To select a pair of lady's 5D lasts with lower heel pitch height from Clarks' current range, and "sensible" shoes from this last.
- To obtain last and to take the joint, waist, and instep girth measurements from this last.
- To duplicate the 5D last shape with different fittings in joint, waist, and instep girth circumference ie. 5B, 5C, 5E, 5F, the differences between fittings being $^1/_4$ inch (about 6.5 mm) interval.
- To make shell shoes on these lasts, the topline style to be cut by referring to a selected shoe (Clarks' Nocturne style).
- To select 20-30 subjects of nominal 5D size and fitting for fitting trials.
- To measure joint, waist, and instep girth of these subjects' feet together with overall foot length, heel to ball length, joint and seat width from both weight-on and weight-off position.
- To look at possible correlation of last allowance vs. weight-on and weight-off factors.
- To record and analyse the results both from measurements and fit assessment.

The procedure of this study is presented as follow (**figure 5.1**).

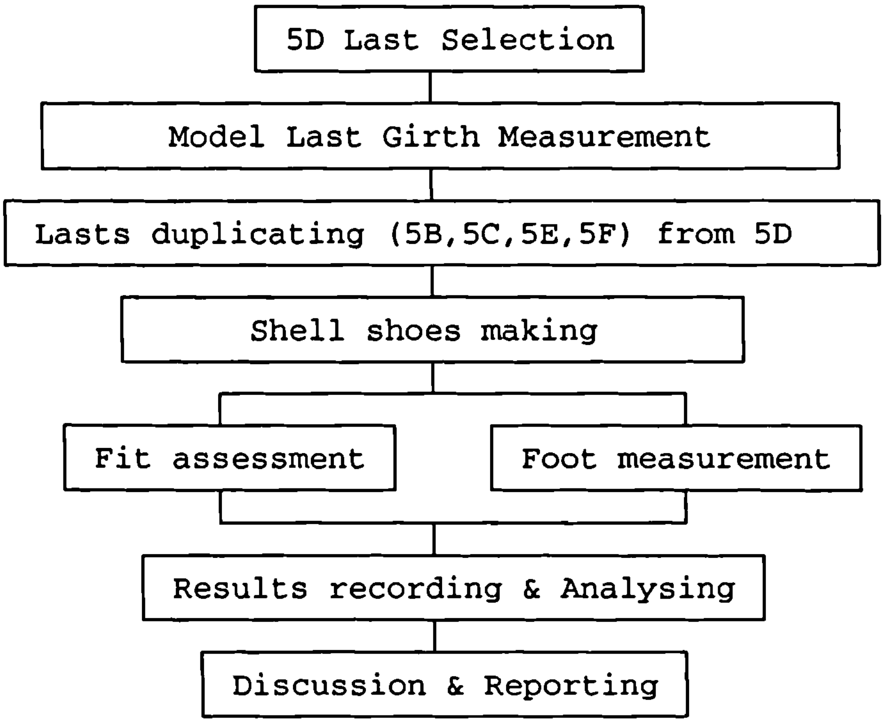

Figure 5.1: TRIAL PROCEDURE OF THIS STUDY.

5.3.1 Last selection and girth measurement

From the results of the shell shoe fitting trial (see *Chapter 4, Section 4.4*), the averaged last allowances (4 model lasts) for all the acceptable and the unacceptable fit in joint girth measurements is shown in **table 5.1.**

Last model	**8676D**	**8933**	**9036/2**	**8892**
Average of d(JG)	-15.8mm	-2.6mm	-3.2mm	0.2mm
Standard deviation	6.6	4.8	5.2	4.7
Number of samples	16	20	20	20

Table 5.1: AVERAGE FOOT/LAST DIFFERENCES IN GIRTH MEASUREMENTS FOR FOUR DIFFERENT MODEL LASTS.

The negative data show that the averaged joint girth measurements of the foot (*foot.x*) are bigger than those of the last (*last.x*). The last-8892 (Nocturne style), where there is an average only 0.2 mm (*SD= 4.66 mm, n=20*) difference between the last and foot, was chosen for these extended studies, because it relates to the normal orthopaedic practice of making shoe last at least as large as the feet (ie. having positive last allowance in girth region). Therefore, the last-8892 which has been measured entirely for model last design and making especially in the girth regions of joint, waist, and instep position is selected for this trial. For commercially sensitive reasons we withhold all data of the last; only the differences between neighbouring fitting in respect of seven required items are listed for discussion.

5.3.2 Girth-ranged last modification

These girth-ranged lasts (5B, 5C, 5E, 5F) were duplicated from the 5D standard model last-8892 by the researcher and Mr. M. Francis and Mr. T. Vowles, senior model last makers of C&J Clarks' last laboratory (former Avalon Components Ltd.), Castle Cary, Somerset, using the UK method of making bespoke last. The process starts with preparation of the standard model last and the contour checking templates (ie. toe, bottom, joint and heel curve). The materials for the last duplicating and modifying are listed in **table 5.2.**

Items	**Quantity**	**Remarks**
Standard model last (8892/5D)	1 pair	Clarks' current range
Canadian maple blocks[4]	10 blocks	see figure 5.2
Fabric tape	1 roll	25 - 40 mm wide
Heel pitch blocks	1 pair	for 8892/5D
Nails with both ends rounded	20 pieces	12.5 mm ($^1/_2$ inch)
White rigid plastic (PVC) sheet	20 pieces	2 mm thick
Steel toe-plates	10 pieces	1.5 mm thick

Table 5.2: MATERIALS FOR LAST DUPLICATING & MODIFYING.

[4] The Canadian maple trees are felled and sawn into logs or spokes. When properly dried and seasoned the logs or spokes are chopped or turned into the rough last shaped blocks.

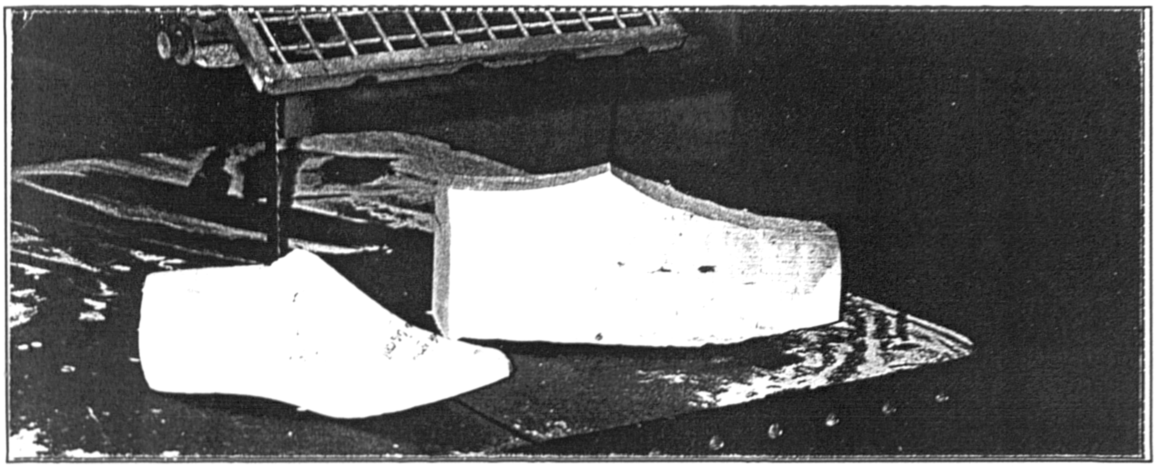

Figure 5.2: THE STANDARD MODEL LAST & SAWN BLOCK.

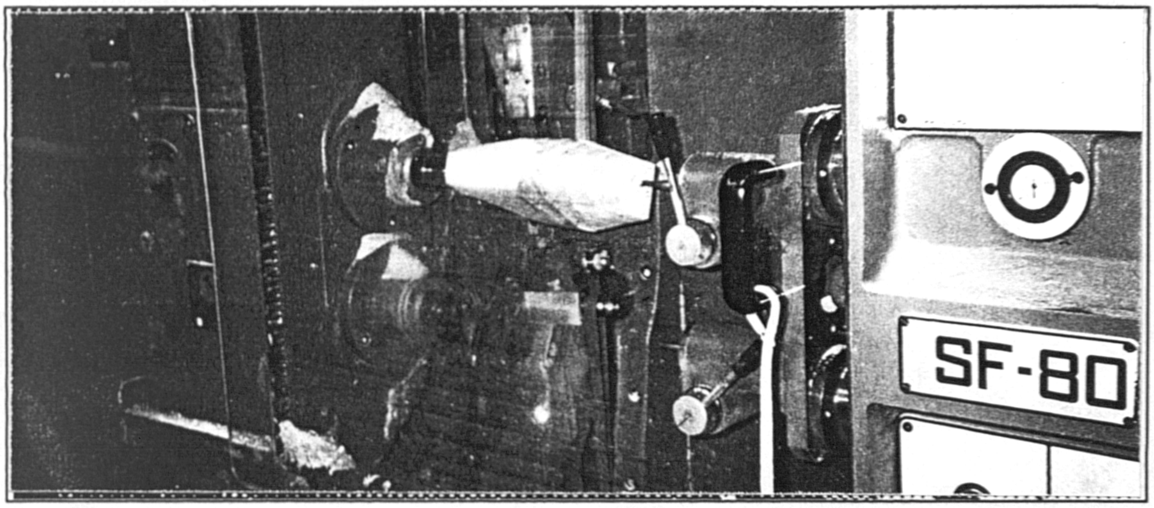

Figure 5.3: THE LAST COPY LATHE (SF-80).

To make (duplicate) the lasts, a special last copy lathe machine is required. **Figure 5.3** shows the last copy machine (SF-80 lathe) which is available from all last manufacturers in the UK. The last copy lathe consists of a pair of rapidly rotating (milling) cutters. The model last and the block are rotated at the same speed. The lathe has a pantograph facility which enables lasts to be copied both smaller and larger than the model last in length and girth for producing a range of sizes and fittings. The model last duplicating procedure is specified as follows:

Preparation:

(1) The standard model last is prepared with the greatest possible care. The locations for measurements are marked by round headed nails driven into the vamp-point, medial and lateral metatarsal-head points of the model last, which can be reproduced on the

turned last at the relative positions. Along the edges of the featherline, nails are driven in very close to each other, and then filed off to reinforce the correct contours of the model. Furthermore, a steel toe-plate is fixed to the bottom of the toe to protect the model when in use, and prevent the destruction of the shape and edges of the model last.

(2) After the standard model last has been prepared, it is first necessary to produce contour templates for checking the duplicated lasts. The templates enable the model last maker to get the same shape for both the standard last and the duplicated one. Normally four basic contour checking templates are required: toe, bottom curvature, joint bottom curvature and heel curve. To make contour checking templates, a scriber block (as illustrated in *Chapter 2*, **figure 2.12**) is required. First the model last is laid and fixed firmly at the required position, and the white rigid PVC sheet is placed under the model last, and the profiles are drawn on this sheet (see **figure 5.4**). After the contours are drawn, these templates are carefully cut to the required size and shape.

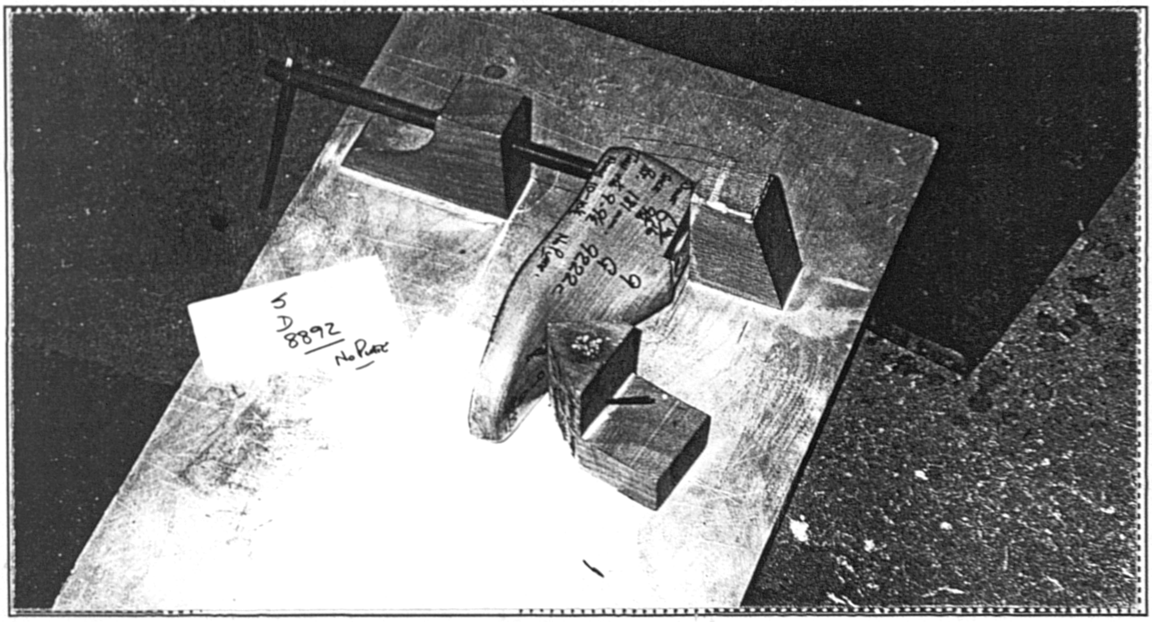

Figure 5.4: TEMPLATES MAKING.

<u>Modification:</u>

(3) The shape of the bottom ie. relation of the forepart to the heel is fundamental in all lasts. This shape should combine with the bottom curvature in the making of suitable footwear. It is divided into three areas ie. seat, waist, and forepart. The length of each

part in relation to the others depends on the type of the shoe (or foot), the height of the heel, and the construction of the footwear. In model last making or duplicating, the shape of the bottom (insole) pattern is usually designed and produced first; then the last is made to fit it. In order to keep the shape of the last during the fitting grading, two sets of bottom (insole) patterns, according to the range used in British shoe last trade, are adopted in this trial. The first one is the 5D set for the fittings 5D, 5E, & 5F; the other is the 5B set for the fittings 5B and 5C (see **figure 5.5** for details). The 5B bottom pattern is graded down from the standard 5D by automatic grading machine with the length being kept constant. The width of the B fitting is $^1/_6$ inch (4.23 mm) narrower than that of the D fitting.

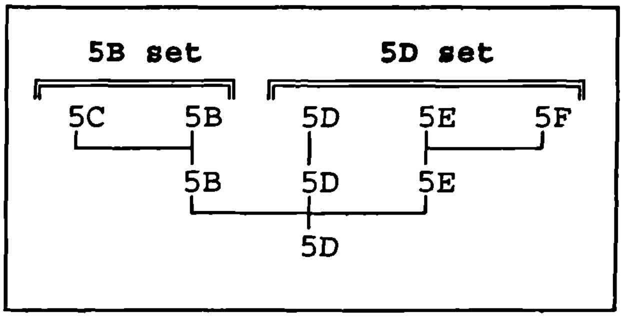

Figure 5.5: INSOLE PATTERN SETS.

(4) To duplicate the shape of the bottom is simple. First, the model last is laid in the bottom-up position, and the outline of the featherline is checked. If the featherline is not clear enough, then its outline can be marked on the last with a soft (6B) pencil. If the waist region is not distinct (but the forepart and seat are clear), then the featherline need to be interpolated. When the bottom is prepared, a piece of card board is fixed to the bottom of the model last, using tacks supported by washers (paper or leather), then the card at the forepart-bottom of the last is pressed and rubbed, so the outline is marked on the paper at the same time. The outline of the seat and waist is taken in a similar way. After the outline of the forepart, seat and waist has been taken, the card is removed from the model and the bottom pattern is cut out carefully. It is better to cut on the inside of the outline adjacent to the last featherline rather than the outside, to avoid error due to the thickness of the paper used and the thickness of the pencil line when reproduced.

(5) The copy lathes can easily duplicate the model last to the required fitting. With straight grading-down, the 5B model last can very quickly be obtained from the 5D model. But the copy lathes might cause some distortion, especially at the forepart of

joint bottom when both bottom curvature and heel pitch height are required to keep the same shape. It is always necessary to modify the forepart bottom region of the 5B model. The modifying work may consist of either removing wood from the upper or adding to the bottom. Adding is usually achieved by building it up with layers of fabric tape (or resin filler). Measuring tape and the templates should be applied all the time to guarantee a correct shape and measurements.

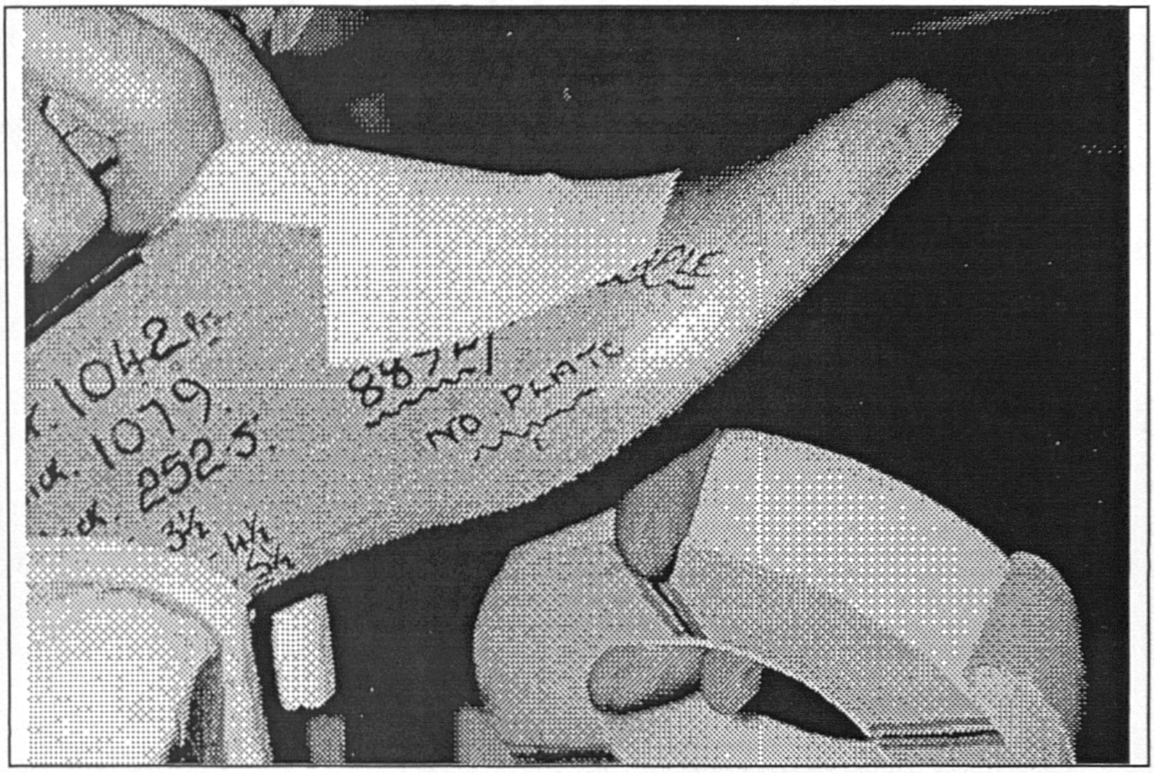

Figure 5.6: BUILD UP FABRIC TAPE ON THE LAST.

(6) After the 5B model is made, the 5C model can then be duplicated from 5B. In the same way, 5E and 5F can be duplicated from the 5D and 5E models respectively. The grading procedure is specified as follows: (i) To take and record the measurements of joint, waist, and instep girth. (ii) Drive the round headed nails into the locations of vamp-point, medial and lateral metatarsal-head point allowing 3 mm ($^1/_8$ inch) of the nail outside the last surface. (iii) Build up the fabric tape on the forepart of the model (see **figure 5.6**), and blend the tape smoothly from the forepart cone region (as a centre) to the toe and the seat (quarter) regions. (iv) Check the toe shape by using toe template. (v) Check the topline by using measuring tape. (vi) Take and record the measurements of joint, waist, and instep girth. (vii) Produce these models by using the copy lathes.

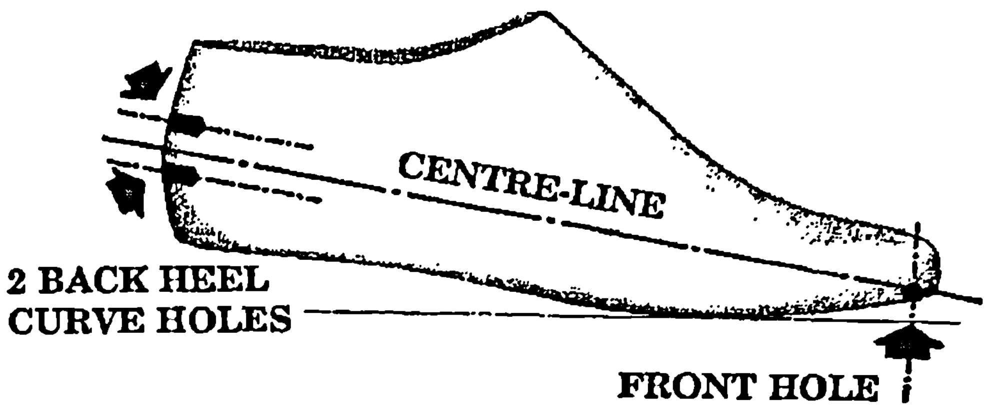

Figure 5.7: FRONT & BACK CURVE LOCATION HOLES.

(7) Having produced a range of model lasts, the duplicating of lasts can be started. First, a steel toe-plate is prepared on the bottom of the model last to prevent the destruction of the model when drilling the front location hole. A line is imagined through the centre of the model from the toe to the back curve point. **Figure 5.7** shows the centre line and the position of the front and back curve location holes. The model is then prepared by drilling one hole in the prepared toe-plate at the front of the bottom related to one end of the centre line. The hole is used to hold the toe of the model in the lathe. Two holes are drilled at the back curve region of the model to hold the model in the lathe. Between these two holes, a probe marker is pointed in the middle at the other end of the centre line.

(8) When prepared, the model last is mounted under the tracing wheel (**figure 5.8**) of the copy lathe machine. Also, a pair of Canadian maple blocks are mounted on the parallel axes under the milling cutters. First the rough blocks are turned forwards at a very quick speed to remove most of the superfluous wood, making a rough duplication about 3 mm ($^1/_8$ inch) oversize. Then the model last is turned backwards at a very slow rate to duplicate the correct shape finely. When the model is dismounted, there remains

the superfluous wood used to hold the model last (ie. the dog[5]) between the two ends of the centre line. Cut the toe dog off and use the prepared bottom pattern to shape the toe. Remove the heel dog and carefully modify the back heel curve with the prepared template to ensure that the correct shape is achieved. Sandpaper is used for the final finishing eg. smoothing the traces of the grooves left by the copy lathe machine, and any other marks resulting from the last making process. This is done entirely by hand, requiring a very fine skill. The lasts are polished and the round headed nails are driven in at the positions of measurement on the model (ie. vamp-point, medial and lateral metatarsal-head point).

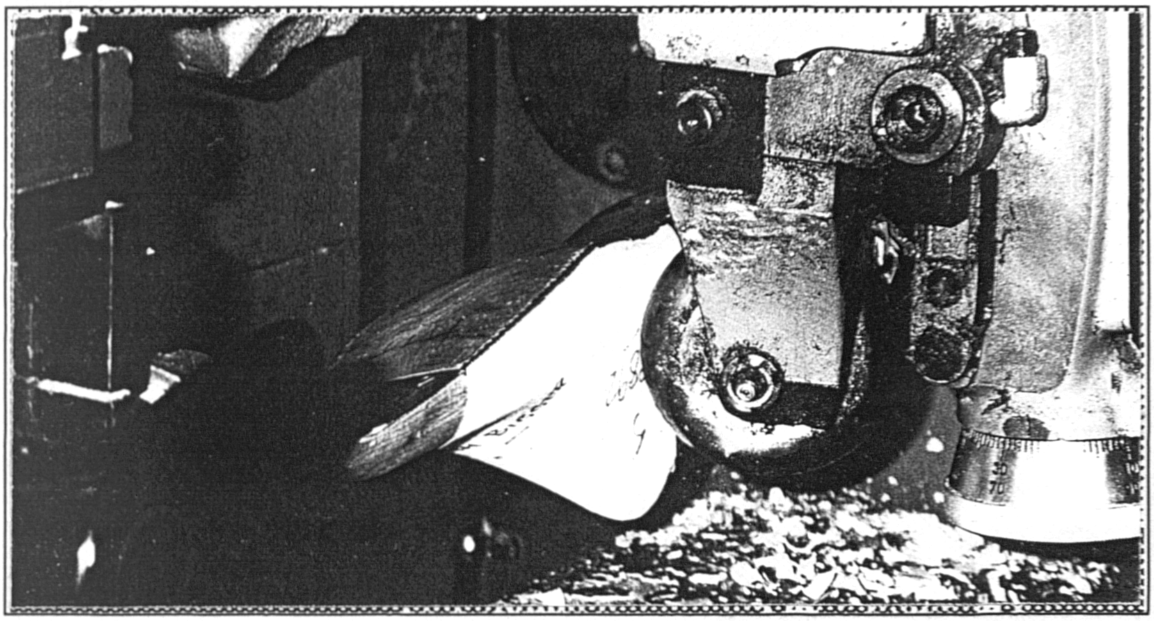

Figure 5.8: TRACING WHEEL.

5.3.3 Shell shoe making

The shell shoe making procedure has been specified in *Chapter 4, Section 4.3.4*. But, the use of upper material is different, the shell shoes here being made from a soft EVA (higher density) sheet with a thickness of 4 mm. These shell shoes are made at Centrum voor Orthopedietechniek Amsterdam (RCA) in the Netherlands and are suitable for

[5] The dog of the last: A special mechanical device for gripping or holding the last during duplicating, esp. the toe-dog at the front end of the last by which the shaft is engaged to transmit torque.

walking trials. The topline style and the forepart opening area (from topline instep-point to vamp-point) of these shell shoes is determined with reference to the original style of Nocturne shoe (which is lasted on the 5D model), and the style rules observed at the RCA (which have been documented in *Chapter 2, Section 2.6*) and anything necessary for this trial[6].

5.3.4 Subjects selection and foot measurement

C&J Clarks International Ltd. provided 10[7] normal 5D fitting trial subjects for this trials; another 13 subjects (5D12 to 5D24) were selected from Department of Fashion and Footwear Design, De Montfort University. 15 subjects are aged 16-25, 6 aged 26-35, and 1 each in age groups 36-45 and 46-55. All the feet were measured using methods similar to those in volume shoe manufacturers and the orthopaedic trade. The measurements are mainly in girth regions including joint girth, waist girth, and instep girth. For what are referred to hereafter as the last allowances, the overall stick length, medial heel to ball length, joint width, and seat width were also measured, both last and feet.

5.3.5 Fitting trials

The fit of these shell shoes was assessed in girth (joint, waist and instep) areas with the subjects sitting, standing and walking. The capital letters (ie. *B, C, D, E, F*) represent the range of different girth fittings for these shell shoes and model lasts (8892). Firstly, a pair of shell shoes were selected by comparison with subject's joint girth measurement. Then other pairs, both narrower or wider, were tested until they were unacceptable (ie. too loose or too tight).

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[6] Special care must be paid at the position of lateral under ankle height and the front opening area which is cut from instep point to vamp point on the joint girth.

[7] 9 of these 10 subjects (5D01 to 5D10) are the same as in the *Shell Shoe Trials*, their feet having been measured in detail; only one subject (5D03) was not available.

It is difficult and unnecessary to produce a series of lasts with half fitting which is in the middle of two neighbouring fittings because half fitting is only $^1/_8$ inch (about 3.2 mm) which is too close to be made and be assessed accurately. Therefore, a notional half fitting set (ie. *b/c, c/d, d/e, e/f*) are used for assessing the fitting between two pairs (eg. fitting *b/c* indicates an interpolated fitting between *B & C fitting*).

In the case of subject-5D01, for example, 5D and 5E shells were firstly selected[8] for assessing fit. It appeared that the 5D shells were slightly tight and 5E shells were slightly loose, but both of them were acceptable. Then the subject was asked the question "*Which shoes would you buy?*". First she was asked to select a pair of best-fit shells from the two acceptable trialled shoes, then to select from the chosen trialled shoes and an additional pair which is assumed with half fitting (ie. d/e) between D&E. A special girth fitting assessment chart (see *Appendix V-I*) was designed for this trial.

[8] The joint girth of 5D is 227.5 mm, 5E is 234.0 mm and the joint girth of 5D01 is averaged 237.0 mm.

5.4 Results

These five model lasts (size 5 with fitting ranges from B to F) are measured. The differences of the measurements between neighbouring fittings are listed in **table 5.3**.

d(x)	d(C-B)	d(D-C)	d(E-D)	d(F-E)
Stick Length	0.0	0.0	0.0	0.0
Medial Heel to Ball	0.0	0.5	0.5	0.0
Joint Girth	6.5	6.5	6.5	6.0
Waist Girth	7.0	6.0	6.0	6.5
Instep Girth	6.5	6.0	6.5	6.5
Joint Width	1.5	1.5	2.0	1.5
Seat Width	0.5	2.5	0.5	0.5

Table 5.3: THE DIFFERENCES BETWEEN NEIGHBOURING FITTINGS (unit: mm).
d(C-B): differences between C & B fitting.
d(D-C): differences between D & C fitting.
d(E-D): differences between E & D fitting.
d(F-E): differences between F & E fitting.

Table 5.4(A) to table 5.4(G) show the detailed foot measurements of all 23 (5D) subjects.

FOOT (STICK) LENGTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	237	235	243	242
5D02	238	236	243	242
5D04	236	235	241	238.5
5D05	235	236	241	244.5
5D06	239	240	245	247
5D07	236	234	241	241
5D08	235	236	241	243
5D09	233	237	240	245
5D10	234	235	240	241.5
5D11	234	235	239	241
5D12	231	232	237	235
5D13	236	235	242	241
5D14	242	240	248	245
5D15	240	241	245	245
5D16	236	236	241.5	241
5D17	238	236	243	242
5D18	239	244	245	251
5D19	235	235	239	241
5D20	234	237	241	242
5D21	238	232	243	238
5D22	238	238	246	246
5D23	239	241	245	247
5D24	236	235	240	239
AVERAGES	236.5	236.6	242.1	242.6
	236.6		242.4	

Table 5.4(A): RESULTS OF 5D SUBJECTS' FOOT LENGTH MEASUREMENT.

MEDIAL HEEL TO BALL LENGTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	172	168	173	170
5D02	176	173	177	175.5
5D04	170	166	170	166
5D05	171	173	171.5	177
5D06	176	173	176	176
5D07	175	170	175	170
5D08	169	169	171	172
5D09	167	170	168	176
5D10	170	171.5	171	172.5
5D11	172	172	173	174
5D12	162	168	167	169
5D13	170	170	171.5	171
5D14	173	171	175	173
5D15	173	173.5	174	.174
5D16	170	170	172	172
5D17	171	170	173	173
5D18	171	173	173.5	175
5D19	171	165	171	167
5D20	166	167	167	169
5D21	162	169	162	169
5D22	173	169	177	175
5D23	175	174.5	175	177
5D24	169	170	173	171
AVERAGES	170.6	170.2	172.0	172.4
	170.4		172.2	

Table 5.4(B): RESULTS OF 5D SUBJECTS' MEDIAL HEEL TO BALL MEASUREMENT.

JOINT GIRTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	235	239	236	239.5
5D02	229	222	231	225
5D04	239	236	245	240
5D05	234	233	239	239
5D06	230	231	235.5	236
5D07	231	231	238	236
5D08	216	217	224	224
5D09	235	234	237	237
5D10	228	221	231	229
5D11	231	231	235	234
5D12	221	223	227	225
5D13	221	220	231	229
5D14	224	223	230	228
5D15	217	218	224	223.5
5D16	217	216	225	225
5D17	223	221	230	229
5D18	229	230	239	235
5D19	219	220	225	227
5D20	222	222	227	227
5D21	218	219	225	224
5D22	231	228	234	230
5D23	229	228	238	239
5D24	225	223	228	226
AVERAGES	226.3	225.5	231.9	230.7
	225.9		231.3	

Table 5.4(C): RESULTS OF 5D SUBJECTS' JOINT GIRTH MEASUREMENT.

WAIST GIRTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	229	229	231.5	234.5
5D02	220	218	225	222
5D04	234	230	239	235
5D05	220.5	225	225	232
5D06	229	228	235.5	233.5
5D07	227	227	236	232
5D08	211	212	220	219.5
5D09	232	229	235	232.5
5D10	216.5	213	221	217
5D11	229	230	230	230
5D12	218	221	224	223
5D13	219	219	230	229
5D14	223	221	226	225
5D15	215	215	221	222
5D16	213	213	222	221
5D17	220	220	229	227
5D18	224	224	231	230
5D19	214	216	218	220
5D20	220	219	225	229
5D21	212	212	218	217
5D22	224	220	224	222
5D23	225	219	229	226
5D24	218	215	223	221
AVERAGES	221.4	220.7	226.9	226.1
	221.1		226.5	

Table 5.4(D): RESULTS OF 5D SUBJECTS' WAIST GIRTH MEASUREMENT.

INSTEP GIRTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	230	233	233	238
5D02	219	224	222	225
5D04	237	238	236	235
5D05	233	232	231.5	237
5D06	229	228	233.5	231
5D07	226	234	233	235
5D08	213	213	223	222
5D09	231	236	238	232
5D10	231	223	232	228
5D11	230	230	234	233
5D12	222	222	224	224
5D13	222	221	233	231
5D14	221	221	228	227
5D15	222	223	229	229
5D16	217	217	223	223
5D17	222	221	228	228
5D18	230	230	231	234
5D19	228	228	227	230
5D20	229	231	228	231
5D21	229	224	221	224
5D22	228	225	232	231
5D23	224	228	231	229.5
5D24	222	223	224	223
AVERAGES	225.9	226.3	229.4	229.6
	226.1		229.5	

Table 5.4(E): RESULTS OF 5D SUBJECTS' INSTEP GIRTH MEASUREMENT.

JOINT WIDTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	88.5	89	91.5	92.5
5D02	85	84.5	87.5	87.5
5D04	86	86	91.5	92
5D05	88	87	95.5	94
5D06	85	87	88.5	92
5D07	86	88	92	92
5D08	82.5	82.5	89	90
5D09	88	88	91.5	92.5
5D10	83	81.5	85	85
5D11	87	87.5	90	91.5
5D12	83	83	84.5	85
5D13	82	81.5	89	89
5D14	84	82.5	91	90
5D15	81.5	83	89	89
5D16	81	81	88	87.5
5D17	81.5	81	89	89
5D18	84.5	86	88.5	90
5D19	81.5	85	86	87
5D20	84	82	89	88
5D21	81	80	86	84
5D22	83	83	88	87
5D23	89	86.5	93	92
5D24	84	83.5	88	87.5
AVERAGES	84.3	84.3	89.2	89.3
	84.3		89.3	

Table 5.4(F): RESULTS OF 5D SUBJECTS' JOINT WIDTH MEASUREMENT.

SEAT WIDTH (unit: mm)				
SUBJECTS	WEIGHT-OFF		WEIGHT-ON	
	RIGHT	LEFT	RIGHT	LEFT
5D01	59.5	58	65	62
5D02	61	59	65	62
5D04	60	59	62	62
5D05	62	62	64	66
5D06	65	63.5	67	66
5D07	61	61	66	63
5D08	59.5	59	61	61
5D09	64.5	63	67	67.5
5D10	59	57	61	60
5D11	58	58	62	63
5D12	56	56	59	58
5D13	60	59	62.5	62
5D14	61	60	62.5	62
5D15	59	59.5	61	61
5D16	56.5	56.5	59	59
5D17	60.5	60	64	64
5D18	59	58	60	60
5D19	57	57	62	60
5D20	60	60	63	63
5D21	58.5	58.5	61	62
5D22	56	58	62	63
5D23	60.5	62	62	65.5
5D24	55	55	57	58
AVERAGES	59.5	59.1	62.4	62.2
	59.3		62.3	

Table 5.4(G): RESULTS OF 5D SUBJECTS' SEAT WIDTH MEASUREMENT.

The fit of these five pairs of size 5 shell shoes (the joint girth increment ranging from *B* to *F fitting*) was assessed by the researcher and supervised by the experienced senior shoe-fitters, Mr. J. Talbot and P. Tazewell, from the Department of Fitting Service, C&J Clarks Ltd., in accordance with an appropriate procedure[9] (see *Appendix V-II* for the details of the girth fitting assessment).

All fitting results are listed in **table 5.5**, where a score of **1** indicates acceptable fitting (ie. *AO+*, *OK*, *AO-*), a score of **0** indicates unacceptable fitting (ie. *UA+* and *UA-*), and an asterisk mark (*) indicates the location of best-fit (ie. *OK*). To normalise the fitting results, **table 5.6** indicates the range of girths (widths) which fit each subject centred on the best-fit fittings.

Table 5.7 presents the results of the acceptable fitting boundaries which is applied from **table 5.6**. The increasing boundaries, *d(AO+)*, are calculated between the joint girth measurements of the centred best-fit (*OK*) and the furthermost acceptable fitting ($AO+_{max}$). Also, the decreasing boundaries, *d(AO-)*, are calculated between the centred best-fit and the furthermost acceptable fitting ($AO-_{min}$). There are two acceptable fitting boundaries for each subject, the increasing boundary which marks the acceptable level of looseness and the decreasing boundary marking the acceptable level of tightness. The negative data, listed in column *d(AO-)*, denote the decreasing boundary.

[9] See *Chapter 4: Shell Shoe Fitting Trial.*

Girth fittings	B	b/c	C	c/d	D	d/e	E	e/f	F
5D01	0	0	0	1	1	1*	1	0	0
5D02	0	1	1*	1	1	0	0	0	0
5D04	0	0	0	1	1	1*	1	0	0
5D05	0	0	0	1	1	1*	1	0	0
5D06	0	0	0	1	1	1*	1	1	0
5D07	0	0	1	1	1*	1	0	0	0
5D08	1	1	1*	1	0	0	0	0	0
5D09	0	0	0	1	1*	1	1	0	0
5D10	1	1*	1	1	0	0	0	0	0
5D11	0	0	0	1	1*	1	0	0	0
5D12	1	1*	1	0	0	0	0	0	0
5D13	0	1	1	1*	1	1	0	0	0
5D14	0	1	1	1*	1	0	0	0	0
5D15	1	1*	1	1	0	0	0	0	0
5D16	1	1*	1	1	0	0	0	0	0
5D17	0	1	1	1*	1	1	0	0	0
5D18	0	0	0	1	1	1*	1	0	0
5D19	0	1	1	1	1*	1	0	0	0
5D20	0	1	1	1*	1	1	0	0	0
5D21	1	1*	1	0	0	0	0	0	0
5D22	0	0	1	1	1	1*	1	0	0
5D23	0	0	1	1	1*	1	1	0	0
5D24	1	1*	1	0	0	0	0	0	0
TOTAL	7.0	13.0	16.0	20.0	16.0	14.0	8.0	1.0	0.0
%	30.4	56.5	69.6	87.0	69.6	60.9	34.8	4.3	0.0

Table 5.5: RESULTS OF FITTING ASSESSMENT.

0: unacceptable, too loose/tight (*UA*+ and *UA*-)
1: acceptable but loose/tight (*AO*+ and *AO*-)
1*: best-fit (*OK*)

Fitting boundary	Girth (width) fittings changes from best-fit								
	-2	$-1^1/_2$	-1	$-^1/_2$	0	$+^1/_2$	+1	$+1^1/_2$	+2
5D01	0	0	1	1	1*	1	0	0	0
5D02	0	0	0	1	1*	1	1	0	0
5D04	0	0	1	1	1*	1	0	0	0
5D05	0	0	1	1	1*	1	0	0	0
5D06	0	0	1	1	1*	1	1	0	0
5D07	0	0	1	1	1*	1	0	0	0
5D08	0	0	1	1	1*	1	0	0	0
5D09	0	0	0	1	1*	1	1	0	0
5D10	0	0	0	1	1*	1	1	0	0
5D11	0	0	0	1	1*	1	0	0	0
5D12	0	0	0	1	1*	1	0	0	0
5D13	0	0	1	1	1*	1	1	0	0
5D14	0	0	1	1	1*	1	0	0	0
5D15	0	0	0	1	1*	1	1	0	0
5D16	0	0	0	1	1*	1	1	0	0
5D17	0	0	1	1	1*	1	1	0	0
5D18	0	0	1	1	1*	1	0	0	0
5D19	0	1	1	1	1*	1	0	0	0
5D20	0	0	1	1	1*	1	1	0	0
5D21	0	0	0	1	1*	1	0	0	0
5D22	0	1	1	1	1*	1	0	0	0
5D23	0	0	1	1	1*	1	1	0	0
5D24	0	0	0	1	1*	1	0	0	0
TOTAL	0	2	14	23	23	23	10	0	0
%	0	9	61	100	100	100	44	0	0

Table 5.6: RANGES OF THE GIRTH (WIDTH) CHANGES FOR ACCEPTABLE FIT, AND THE BEST-FIT (*OK*) ARE CENTRED.

For example: subject-5D01 found that the shoe up to half fitting ($+^1/_2$), and one fitting (-1) below were acceptable.

Subject	d(AO-)	OK	d(AO+)	$AO-_{min}$	$AO+_{max}$	d(AO+/-)
5D01	-6.5	230.8	+3.3	224.3	234.0	9.8
5D02	-3.3	221.0	+6.5	217.8	227.5	9.8
5D04	-6.5	230.8	+3.3	224.3	234.0	9.8
5D05	-6.5	230.8	+3.3	224.3	234.0	9.8
5D06	-6.5	230.8	+6.5	224.3	237.3	13.0
5D07	-6.5	227.5	+3.3	221.0	230.8	9.8
5D08	-6.5	221.0	+3.3	214.5	224.3	9.8
5D09	-3.3	227.5	+6.5	224.3	234.0	9.8
5D10	-3.3	217.8	+6.5	214.5	224.3	9.8
5D11	-3.3	227.5	+3.3	224.3	230.8	6.5
5D12	-3.3	217.8	+3.3	214.5	221.0	6.5
5D13	-6.5	224.3	+6.5	217.8	230.8	13.0
5D14	-6.5	224.3	+3.3	217.8	227.5	9.8
5D15	-3.3	217.8	+6.5	214.5	224.3	9.8
5D16	-3.3	217.8	+6.5	214.5	224.3	9.8
5D17	-6.5	224.3	+6.5	217.8	230.8	13.0
5D18	-6.5	230.8	+3.3	224.3	234.0	9.8
5D19	-9.8	227.5	+3.3	217.8	230.8	13.0
5D20	-6.5	224.3	+6.5	217.8	230.8	13.0
5D21	-3.3	217.8	+3.3	214.5	221.0	6.5
5D22	-9.8	230.8	+3.3	221.0	234.0	13.0
5D23	-6.5	227.5	+6.5	221.0	234.0	13.0
5D24	-3.3	217.8	+3.3	214.5	221.0	6.5
Average	**-5.5**	**224.7**	**+4.7**	**219.2**	**229.3**	**10.2**

Table 5.7: CALCULATED RESULTS OF ACCEPTABLE FITTING BOUNDARIES.

Table 5.8 presents the results of comparison of the foot measurements. The averaged differences of the foot measurements (46 feet) between weight-on and weight-off, *AVG(on.x - off.x)*, are also listed. **Table 5.9** shows the results of the averaged differences between the individual best-fit model last measurements and its corresponding foot measurements both at weight-on and weight-off positions.

unit: mm	Weight-on		difference	Weight-off	
	from - to	range	Avg(on-off),n=46	from - to	range
Stick Length	235 - 251	16	5.9	231 - 244	13
Heel to Ball	162 - 177	15	1.8	162 - 176	14
Joint Girth	223 - 245	21	5.5	216 - 239	23
Waist Girth	217 - 239	22	5.5	211 - 234	23
Instep Girth	221 - 238	17	3.4	213 - 238	25
Joint Width	84 - 95	11	4.9	80 - 89	9
Seat Width	57 - 67	10	3.0	55 - 64.5	9.5

Table 5.8: COMPARISON OF FOOT MEASUREMENTS IN WEIGHT-ON AND WEIGHT-OFF POSITIONS.

unit: mm	Avg(foot.x),n=46		Avg(last.x),n=46	Avg(last-foot),n=46	
	Weight-on	Weight-off	Best-fit last	Weight-on	Weight-off
Stick Length	242.4	236.5	252.0	9.6	15.5
Heel to Ball	172.2	170.4	172.5	0.3	2.1
Joint Girth	231.3	225.9	224.7	-6.7	-1.2
Waist Girth	226.5	221.0	223.8	-2.7	2.8
Instep Girth	229.5	226.1	231.5	2.0	5.4
Joint Width	89.2	84.3	82.4	-6.8	-1.9
Seat Width	62.3	59.3	57.0	-5.3	-2.3

Table 5.9 :DIFFERENCES BETWEEN BEST FIT LASTS & FOOT (WEIGHT-ON/OFF).

5.5 Analysis and discussion

Grading of lasts:

The interval between girth measurements for successive shoe widths at joint, waist, and instep areas should be constant. In the UK/USA grading system, the girth increases by $^1/_4$ inch (about 6.35 mm), the length of the size grows by $^1/_3$ inch (about 8.46 mm) and the width by $^1/_{12}$ inch (about 2.1 mm). The lasts used in this trial do not increase by exactly this increment. One of the major causes is that the measuring instruments (eg. size stick, metric measuring tape, etc.) are only accurate within 0.5 to 1 mm. As these model lasts are bespoke, the accuracy also depends upon the manual skills of individuals. In this trial, 1 mm of measuring discrepancy should be allowed.

Range of girth (width) fitting:

Ideally the trial should have been conducted with all subjects of the same girth (width) fitting, ie. a nominal **5D**. From the results of the fitting assessment (see *Appendix V-II*), it is seen that of these 23 subjects, 6 subjects are *b/c fitting*, 2 subjects are *C fitting*, 4 subjects are *c/d fitting*, 5 subjects are *D fitting*, and 6 subjects are *d/e fitting* to achieve the best fitting (*OK*). These results appear to be too widely scattered. To consider the width which fitted the subjects best on average we can note that of the 23 subjects, the *c/d fitting* was acceptable (ie. AO-/OK/AO+) to 20 subjects, which is about 87% in suitability; the *C* and *D fitting* were acceptable to 16 subjects each (69.6% in suitability); the *d/e fitting* was acceptable to 14 subjects (60.9%); the *b/c fitting* was acceptable to 13 subjects (56.5%); the *E fitting* was acceptable to 8 subjects (34.8%); the *B fitting* to 7 subjects (30.4%), and the *e/f fitting* to 1 subject (4.3%). Thus, from the compared fitting assessments,, the *c/d fitting* of **224.25 mm** in joint girth presented the better grading (fitting) centre than the original standard *D fitting* of **227.5 mm**. This group of subjects was therefore on average very close to the nominal **5D**, perhaps $^1/_2$ girth (width) fitting narrower (see **figure 5.9** and **5.10** for the details).

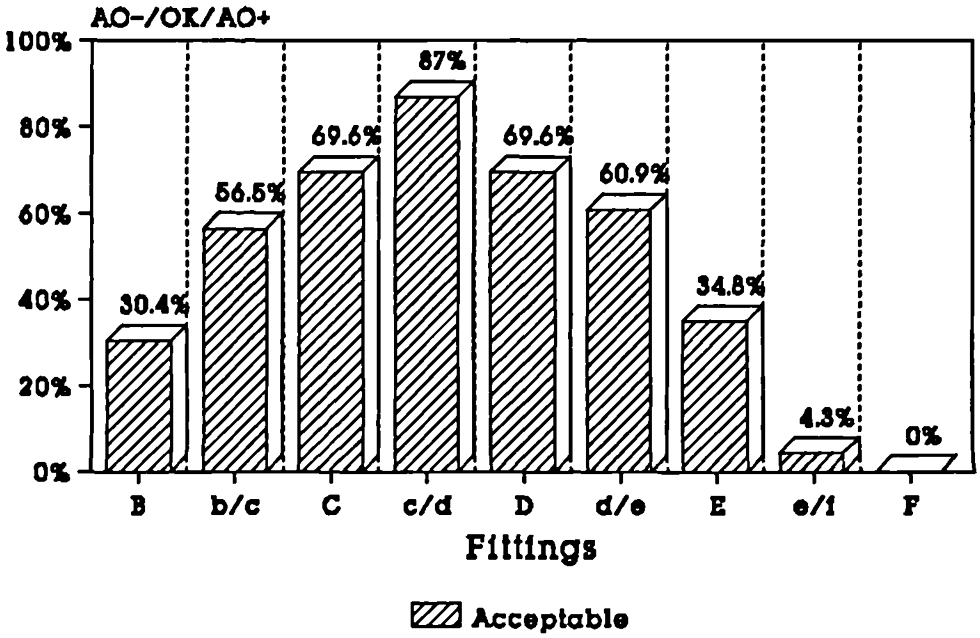

Figure 5.9: THE SUITABILITY OF FITTING ASSESSMENTS (AO-/OK/AO+).

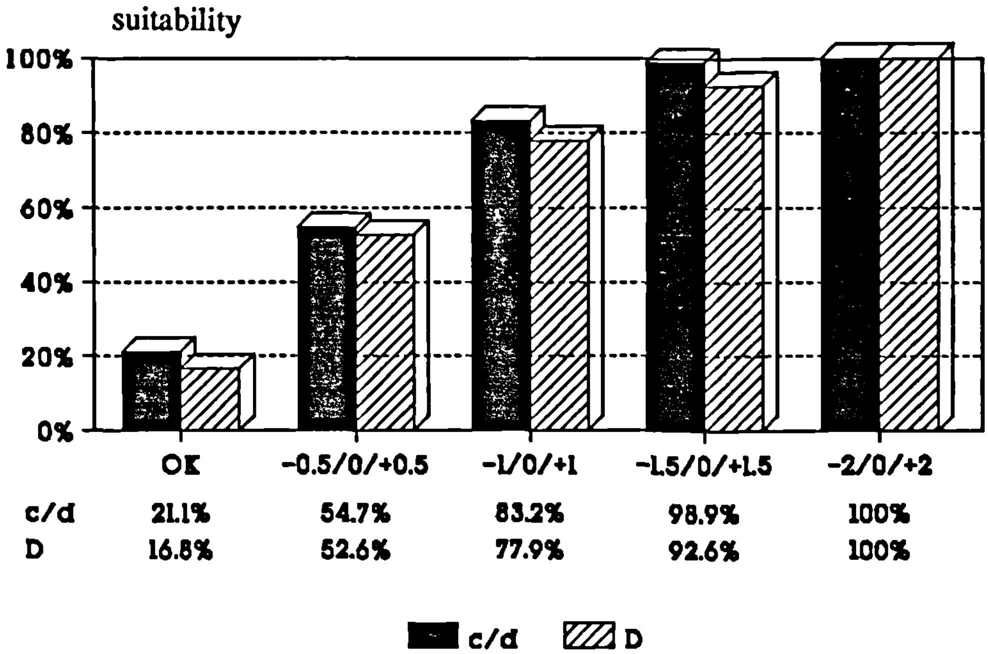

Figure 5.10: THE SUITABILITY OF THE TWO BEST-FITTINGS (*c/d* & *D*).

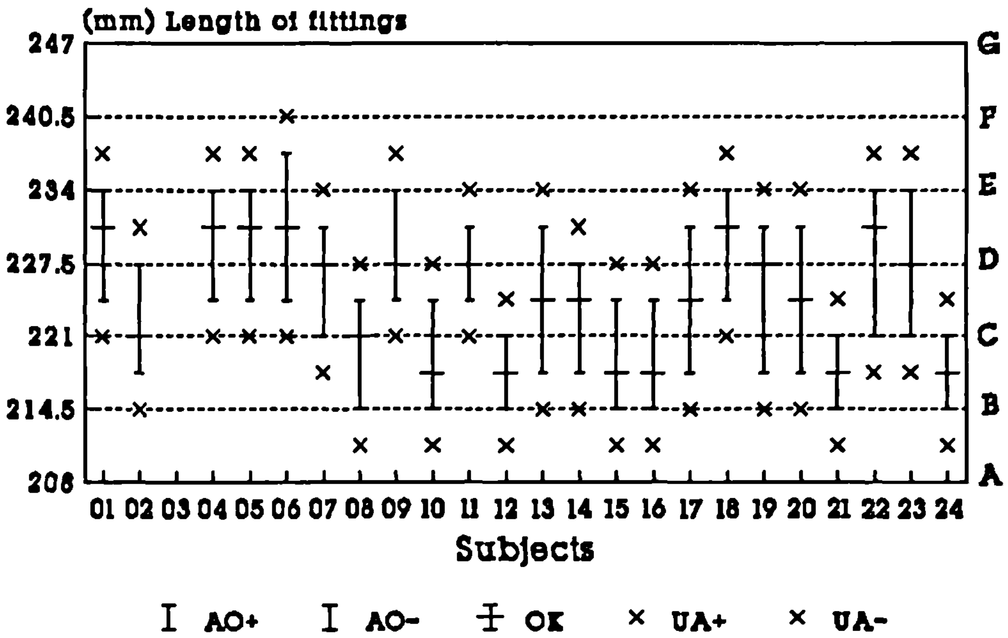

Figure 5.11: RELATIONSHIP AMONG FITTING ASSESSMENTS.

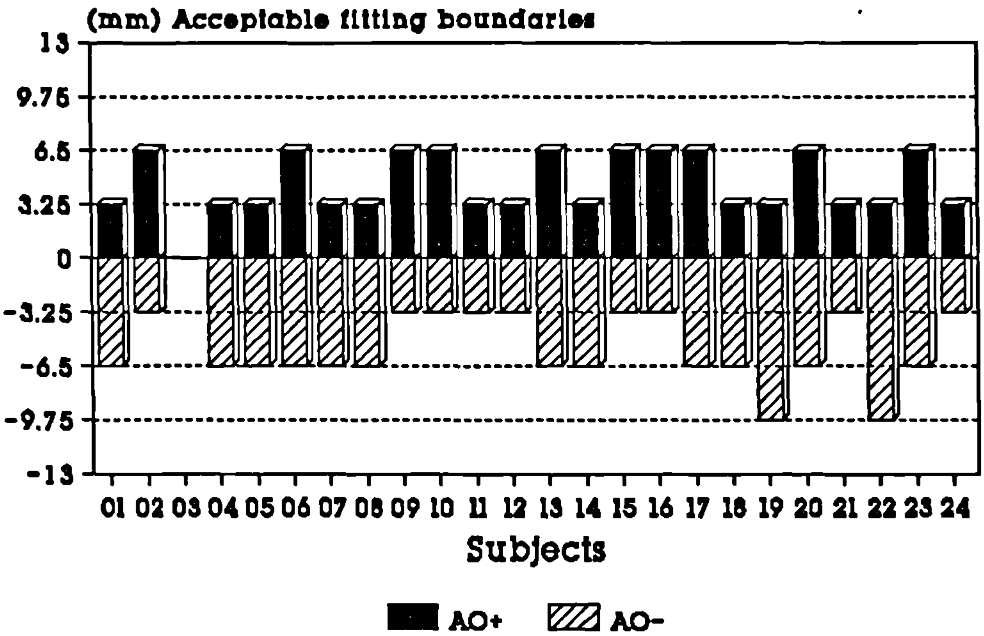

Figure 5.12: CENTRALISED FITTING ASSESSMENT RESULTS.

Limits of tolerable fitting boundaries:

Figure 5.11 explains the relationship between the fitting assessment. **Figure 5.12** shows the re-organised results of fitting assessment, the best-fit (*OK*) being zeroed at the central line between the loose-fitting boundaries (above) and the tight-fitting boundaries (below). In the **loose-fitting** assessment on these 23 subjects (refer to **table 5.6**), all 23 subjects (100%) fell within acceptable boundary of $+^1/_2$ (up to 3.25 mm looser), 10 subjects (43%) within the acceptable boundary of **+1** (up to 6.5 mm looser) than that of the best-fit centre (*OK*) of **0**. In the **tight-fitting** assessment on the same subjects, all 23 subjects (100%) found the $-^1/_2$ boundary (up to 3.25 mm tighter) acceptable, 14 (60.9%) found the **-1** boundary (up to 6.5 mm tighter) acceptable, and 2 subjects (8.7%) fell within the acceptable boundary of $-1^1/_2$ (up to 9.75 mm tighter) than the best-fit centre, as illustrated in **figure 5.13**.

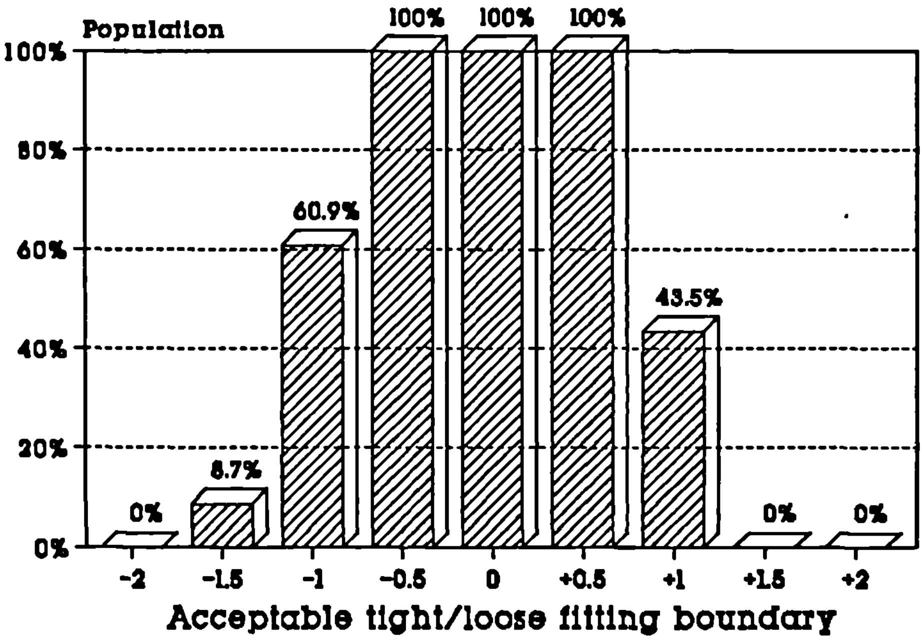

Figure 5.13: THE POPULATION AT EACH ACCEPTABLE BOUNDARY.

Based on the joint girth measurements of the best-fit (*OK*) lasts, an averaged centre can be calculated as 224.7 mm (*n= 23 pairs*) with the acceptable loose-fitting boundary **4.7 mm** and the acceptable tight-fitting boundary **5.5 mm** (refer to **table 5.7**). This indicates that an averaged limit of tolerable fitting range of approximately 10.2 mm is acceptable between 229.4 mm (loose boundary) and 219.2 mm (tight boundary) at the joint girth for nominal 5D subjects.

Weight-on vs. weight-off:

In the case of volume shoe trade, feet are measured either in weight-on or weight-off positions but last allowances must relate to only one of these measurements. The weight-on measurements are normally taken for making men's model lasts and the weight-off measurements for women's and children's lasts. It is strange that the measurements for women's last making are taken in weight-off position but fit assessment are made in the weight-on position. This is similar to orthopaedics (BS-5943). It is, therefore, necessary to study the relationship between weight-on and weight-off measurements.

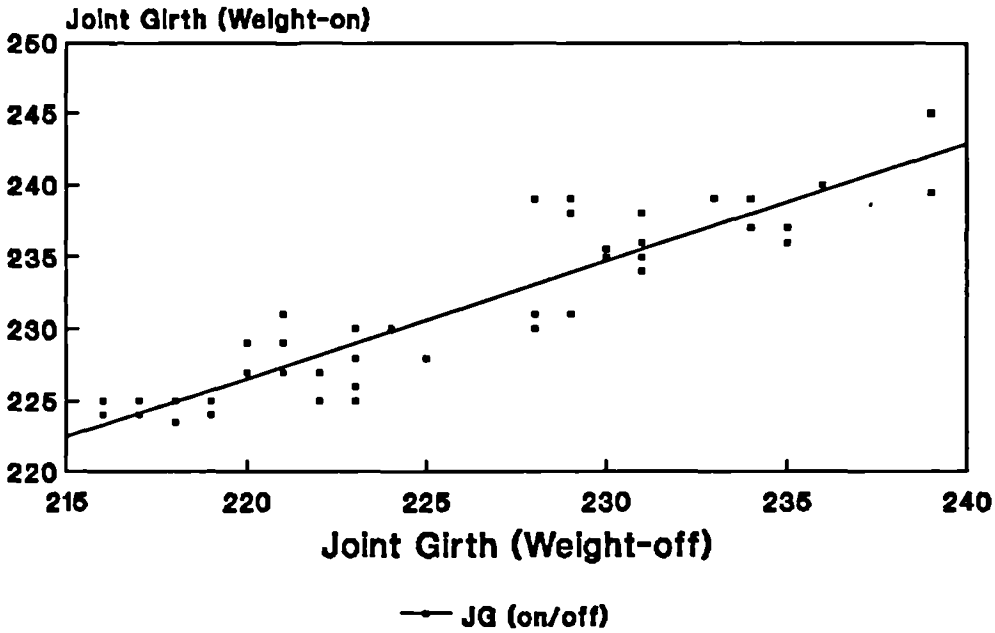

Figure 5.14: THE CORRELATION BETWEEN WEIGHT-ON (JG-on) & WEIGHT-OFF (JG-off) IN JOINT GIRTH.

Figure 5.14 shows the relationship of joint girth measures (46 feet) between weight-on and weight-off positions. The regression line illustrates the trend within those scattered data points *SP(x,y)* as follows.

$$y = 0.81x + 47.27$$

$$r = +0.92, \quad SP(x,y): 216 \le x \le 239,\ 223.5 \le y \le 245$$

The standard error probability can then be calculated as $P < 0.1\%$ ($t = 15.76$, $DF = 44$). The regression equation of this trend-line shows as expected a highly significant correlation.

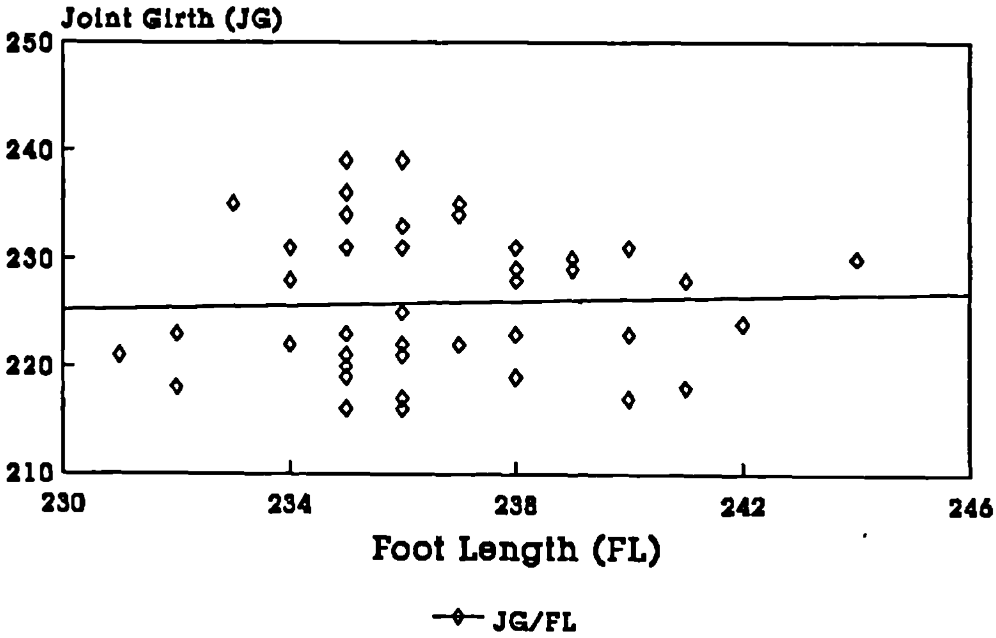

Figure 5.15: JOINT GIRTH (JG) vs. FOOT LENGTH (FL).

Girth vs. length measurements:

Figure 5.15 illustrates the relationship between joint girth and foot length measurements (46 feet) in weight-off position. The regression line illustrates the trend within those scattered data points *SP(x,y)*. The regression equation of this assumed trend-line can be calculated as

$$y = 200.5 + 0.11x$$

$$r = +0.04, \quad SP(x,y): 231 \le x \le 244,\ 216 \le y \le 239$$

The standard error probability of $P > 50\%$ ($t= 0.30$, $DF= 44$) shows a no significant correlation. Similar lack of correlation was found with waist girth, ($r= +0.07$, $n= 46$), and with instep girth, ($r= 0.09$, $n= 46$), which indicate a random scatter between girth and length. However, the subjects were selected from nominal size 5D, and one would expect foot length and girth measurements to be scattered within a limited range (ie. from size $4^1/_2$ to $5^1/_2$ and fitting *c/d* to *d/e*). If the subjects are selected with a wider range of sizes (eg. from ladies' size 4 to 10), there will be an **Envelope**[10] correlation.

Joint girth vs joint width measurements:

Figure 5.16 (weight-off) and **figure 5.17** (weight-on) illustrate the relationship between width and girth measures of 46 feet in joint region. The regression trend-lines show their trend within those scattered data points *SP(x,y)*. The regression equations of these trend-lines can then be calculated as

$$y = 9.43 + 0.33x \qquad (weight\text{-}off)$$

$$r = +0.84, \qquad SP(x,y): 216 \le x \le 239,\ 80 \le y \le 89$$

$$P < 0.1\% \qquad (t = 10.33,\ DF = 44)$$

$$y = 13.13 + 0.33x \qquad (weight\text{-}on)$$

$$r = +0.72, \qquad SP(x,y): 223 \le x \le 245,\ 84 \le y \le 95$$

$$P < 0.1\% \qquad (t = 6.85,\ DF = 44)$$

These indicate highly significant correlation between joint girth and width. Obviously, the joint width measurement can be calculated easily as about $^1/_3$ of joint girth measurement.

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[10] A group of points or curves in a tangential relationship to each one of a group of points or curve.

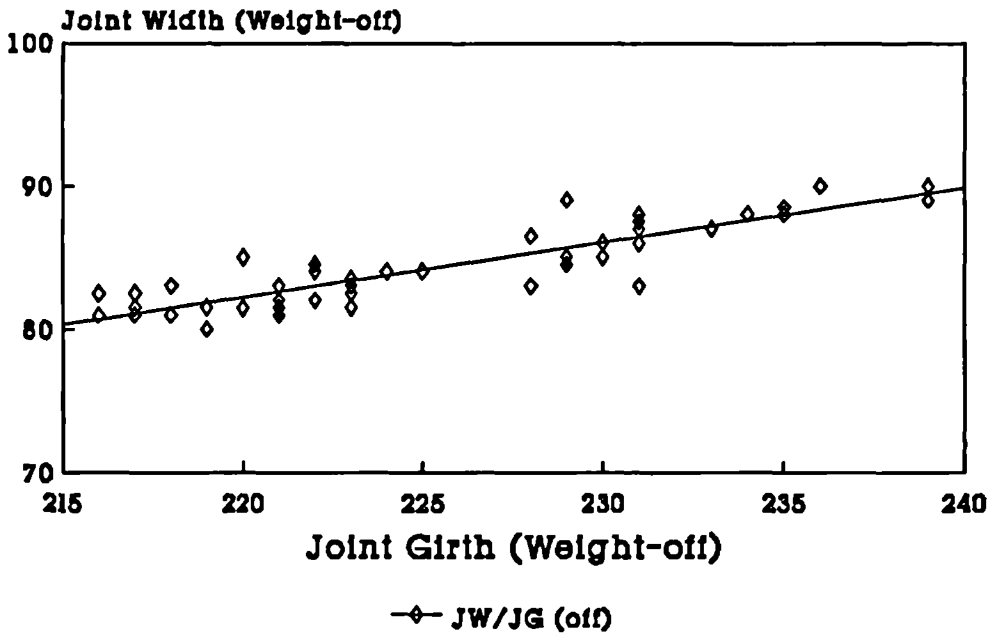

Figure 5.16: JOINT WIDTH (JW-off) vs. JOINT GIRTH (JG-off).

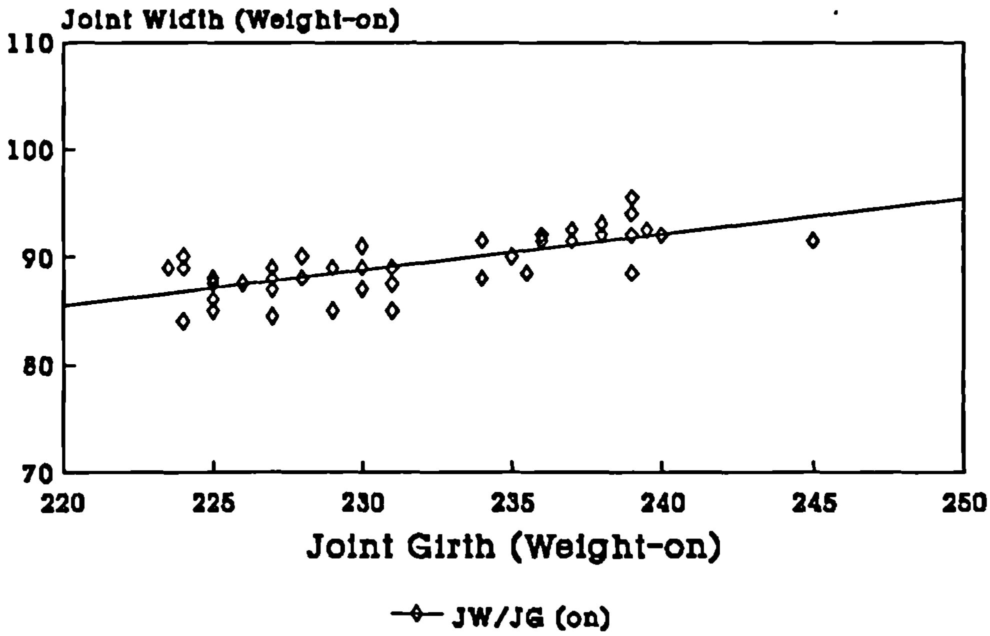

Figure 5.17: JOINT WIDTH (JW-on) vs. JOINT GIRTH (JG-on).

Joint width vs. Seat width measurements:

To enable comparison between patient groups, it is essential to analyse and discuss the normative data. A narrow heel seat width with a wide forepart width is a common fitting problem. If the shoe is fitted at the forepart, then it will be too loose at the backpart. There is no standard footwear available to accommodate such a foot. Therefore the only solution is to buy a pair of shoes with adjustable forepart such as lace-up or bar styled shoes, which will be wide enough to fit the forepart region.

Figure 5.18 (weight-off) and **figure 5.19** (weight-on) illustrate the relationship between seat width and joint width measurements of 46 feet and the regression lines show the trend within those scattered data points *SP(x,y)*. The regression equations of these trend-lines show their significant correlation.

$$y = 25.73 + 0.40x \qquad (weight\text{-}off)$$

$$r = +0.44, \qquad SP(x,y): 80 \leq x \leq 89,\ 55 \leq y \leq 64.5$$

$$0.1\% < P < 1\% \qquad (t = 3.28,\ DF = 44)$$

$$y = 15.63 + 0.52x \qquad (weight\text{-}on)$$

$$r = +0.56, \qquad SP(x,y): 84 \leq x \leq 95,\ 57 \leq y \leq 67$$

$$P < 0.1\% \qquad (t = 4.45,\ DF = 44)$$

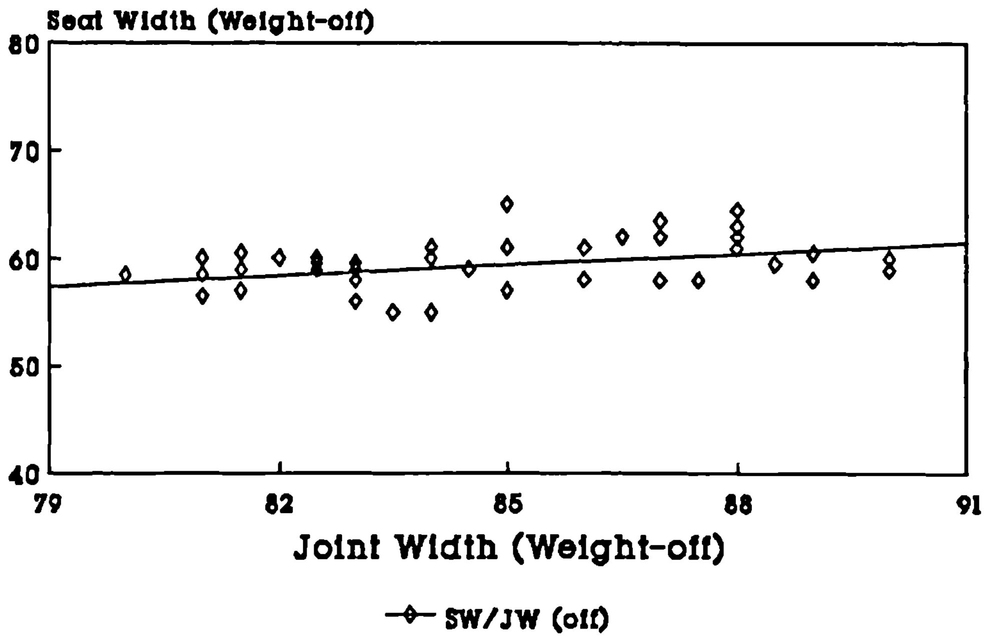

Figure 5.18: SEAT WIDTH (SW-off) vs. JOINT WIDTH (JW-off).

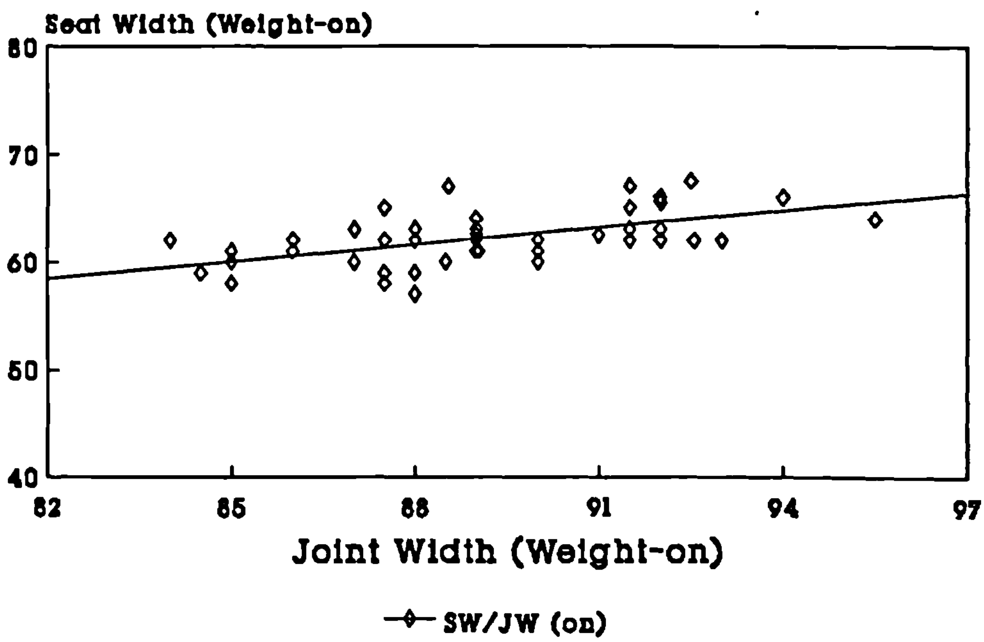

Figure 5.19: SEAT WIDTH (SW-on) vs. JOINT WIDTH (JW-on).

5.6 Conclusions

A method for last and fit assessment was developed to identify the limits of tolerable fitting. Most of the inter-relationship between foot measurements (particularly joint girth and joint width) has also been explored. It will be useful in helping to improve the design of model lasts so that they bear a better relationship to the subjects' feet.

A further, more detailed study, with a greater number of subjects is required to verify its accuracy. However, this trial study has shown this to be a successful method of both last and foot fitting assessment. These normative data can be transferred to orthopaedic patient groups.

CHAPTER 6
IN-SHOE FOOT LENGTH AND TOE ROOM REQUIREMENTS

6.1 Introduction

The most frequent problems revealed by fit assessing trials in the UK are incorrect length and size marking (**Browne & Taylor, 1979**). It is often seen that the foot actually requires a size at least one size longer than the marked size because females especially, for reason of appearance, prefer shorter and narrower shoes, and the shoe will not stay on unless "tight" enough at the joint region. The recent fashion shoe style (**Autumn & Winter 1992/93**) trend for deeper, rounded and natural shaped toes has minimised these fitting problems but this does not solve the problems in footwear sizing. When the fashion trends turn back to narrower styles, these problems still remain.

There should be sufficient space or **toe room allowance**[1] in front of the foot to accommodate the toes without crowding. This sufficient space should, of course, be provided in shoes all the time. Otherwise, the toes are squeezed together and unable to perform their natural function efficiently during standing and walking. Sufficient toe room allowance is a region of length, width and height (depth) at the toe-tip which is determined by the shoe last on which the shoe was built.

Another problem is obtaining a relevant measurement of foot length. In comparison with the length of the foot measured unloaded, there should be an additional measurement to allow for the weight-bearing extension of the foot. To consider the difference of length between the unloaded and loaded foot, it is necessary to have an overview of the foot and the effect of the distribution of body weight on the foot. **Morton (1935)** suggested that the body weight, when standing, is distributed in the ratio of 1:1 between heel and forefoot for each foot. Under each of these weight-bearing points, there are soft tissue cushions (eg. muscle, tendon and fatty pads) that distribute

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[1] Toe room allowance is the space between the toe-tip of the foot and the toe-end of the shoe/last. This space is needed to allow foot movement and shoe style design and, in the case of children, growth (see **figure 6.1**).

the weight evenly. Variations in foot length measurement may be due to the flattening of the longitudinal arches (see *Section 6.5.1* for details). **Shereff et al. (1990)** in their study of comparison of nonweight-bearing and weight-bearing radiographs of the foot point out that in weight-bearing situation, as the arch flattens, the projection of the 1st metatarsal-head onto the support plane is significantly lengthened (eg. an averaged 8.8 mm extension, ranged from 2 to 9 mm in normal subjects, and an averaged 9 mm ranged from 4 to 19 mm in hallux valgus subject groups).

There have been many published investigations into weight-related foot length with a view to providing more accurate study of the foot in its static and dynamic functional mechanism (eg. gait cycle, foot loading and shape changes etc.) but there has been no report published on walking extension at the toe region (ie. toe extension[2]) from heel-lift to push-off phases. Nevertheless, this area is an important factor which influences the toe room allowance in the footwear industry. Without such background of knowledge, the provision of truly adequate footwear will be impossible.

Toe room allowance and foot length measurements are two of the main factors which determine the size of the shoe and last. The measured foot length only gives an indication of the shoe last size: the toe room allowance is affected by many variables. There is no fixed rule which can be applied to the overall foot length measurement and toe room allowance. For example, a pointed-toe shaped last would require longer toe room than a rounded-toe shaped last and a shallow-slanted or receding toe shape design usually requires more toe room allowance, both in the length and width, than a style with a walled toe box.

Figure 6.1 shows the toe room allowance, comprising walking extension (weight-bearing extension plus toe extension) together with the styling requirement. The minimum toe room allowance must be the maximum walking extension which is for the foot moving forward during normal gait and should be applied at the position of toe nail

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[2] Toe extension is the distance which increases in length of the toe during walking.

level because of the shoe receding factor. The greater the toe shape receding, the more distance (ie. T_1, T_2 or T_3) is needed at the toe-end region of the shoe.

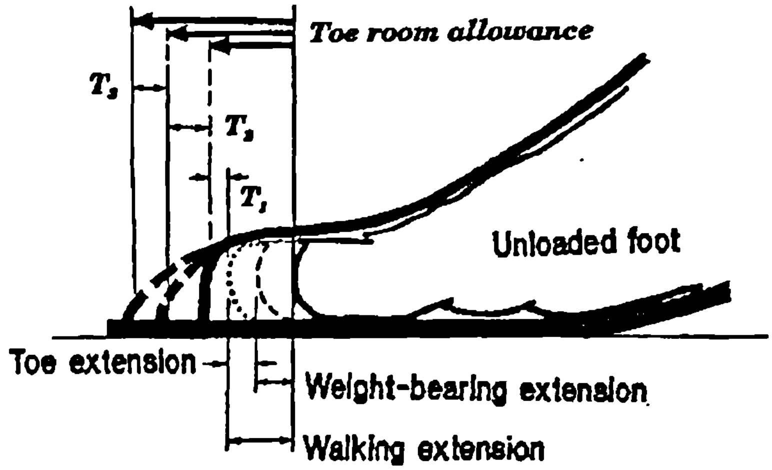

Figure 6.1: TOE ROOM ALLOWANCE IS REQUIRED TO PROVIDE ADEQUATE LENGTH FOR FOOT EXTENSION. WITH MORE TOE SHAPE RECEDE, SOME EXTRA DISTANCE (T1, T2 OR T3) IS NEEDED AT TOE-END REGION.

However, according SATRA's survey (Bulletin, 1981), there is a natural desire to keep the length of the shoe as short as possible. This preference must be overcome in order to achieve satisfactory fit and avoid excessive distortion of the foot. Yet, ironically, this essential measurement of toe extension is usually disregarded by most of the shoe last makers and shoe-fitters due to the lack of an accurate measuring device to measure in-shoe foot extension during standing and walking. This can lead to mis-calculation in last design and manufacture and to ill-fitting shoes.

Based on SATRA Footwear Technology Centre's unpublished suggestions (Larcombe, 1990) for the toe room allowance in children's shoes, about 10 mm gap is needed in front of the toes. With adults' shoes, there is no need for a growth allowance, but a gap in front of the toes is necessary because of the walking extension and styling allowance. The toe room allowance for men's shoes was suggested (by SATRA) as 10 mm (of the same order as children's) and about 5 mm for the women's.

In the high street shoe shop and fitting room, there are many ways to check the toe room allowance between the longest toe and the shoe to allow for the elongation of the foot during walking: (1) Ask the subjects (or customers) from the outside shoe to identify the position in the shoe of their longest toe-tip; (2) Check the shoe and foot length from the gap at the back heel by pushing the foot forward to touch the toe-end of the shoe with the shoe un-fastened; (3) Use a strip of card, and cut to the length of the foot. With the shoe off, the card is then inserted into the shoe. This should reveal a gap between the end of the card and the inside of the heel of the shoe; (4) Powder the insoles with French Chalk lightly before putting on the shoes. After the subject has walked a few steps, check the insoles. A gap between the toe-end of the insole and a clear outline of the toe can be seen and measured; (5) Take a window assessment at the toe region, and either take the measurements or estimate the toe room (see *Chapter 4, Section 4.5.2*); (6) Use the transparent shell shoe assessment to evaluate the toe room (see *Chapter 4, Section 4.3.4*). Methods above provide some ideas to assist the fit assessment for the toe room. However, those are measured only **after** the shoe and the last have been made. An acceptable and accurate toe room allowance is required for the shoe last design and making, particularly **before** or **during** the period when the shoe and the last are made.

These problems can be attacked by developing an accurate in-shoe foot measuring device which will enable the required weight-bearing and moving allowances to be worked out for last model design. In this trial, a pair of shoe was purchased from a Clarks shoe shop and used as the basis for constructing such a measuring device. It was selected under conditions designed to achieve a closer match with the natural bare foot and for ease of installation. The design and development of an in-shoe measuring device for recording these effective foot extensions has been undertaken with assistance from **Orthopaedic Footwear R&D Group** of the Department.

6.2 Aims and objectives

The aim of this study[3] is to develop a length measuring device which is used for measuring weight-bearing and movement allowance of the overall foot length. This research will provide an accurate measure of changes in foot length from sitting to standing and walking, measured from inside shoe.

The specific objectives of this trial are:

- To develop and design a measuring device which can be fixed at the forepart of the shoe.
- To measure the total length of the foot at the positions of sitting (weight-off), standing (weight-on), and walking.
- To record and compare the results of differences between those changes of the foot length.
- To suggest the sufficient toe room allowance for the last design and manufacturing.

[3] This study is associated with EUREKA PROJECT "SELECT".

6.3 Trial protocol

The stages in this trial can be identified as:

- To select one pair of lady's 5D flat instrumented shoes with the lace-up style or other style which enables its topline to hold the foot firmly.
- To develop and design a foot length measuring device, accurate enough to measure the maximum elongation of the foot when standing and walking.
- To install the measuring device on the forepart of the shoe.
- To select 20-30 (5D) normal subjects to fit the trial shoes and measure[4] their feet in sitting, standing and walking positions.

In this experiment, a number of techniques are required ie. foot measurement, selection and preparation of trial shoes and designing, making and installing the measuring device. The materials of this device comprise a plastic vernier caliper (RS), a measuring meter (within 0.1 mm accuracy) etc. The procedure of this trial is presented as:

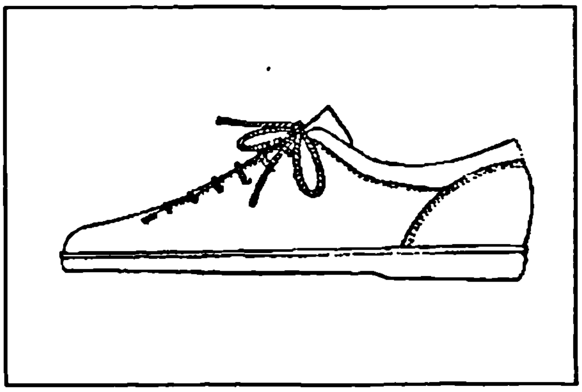

Figure 6.2: SELECTED STYLE.

(1) <u>Trial shoe selection</u>: Firstly, one pair of trial shoes was selected with a shape close to the natural foot shape. The heel pitch of the shoe was chosen to be flat (lower than 1 inch[5]) to provide results relevant to orthopaedics, noting that the foot length extension could vary with different heel pitch height. In order to fit such a wide range of normal subjects (ie. 23 volunteers) in one pair of shoes, it is necessary to adopt a soft upper shoe with lace-up style which is open at the front of forepart cone. The thickness of outsole at the forepart region needed to be thick enough (between 5 mm and 8 mm) in order to give space for the installation of the in-shoe measuring device (see **figure 6.2**).

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[4] The measurements are taken on the right foot only, because there is only one measuring device which is installed on the right trial shoe.

[5] Heel height pitch is measured in eights of an inch (3 mm) as one unit. it is measured from the anterior heel seat point of the bottom.

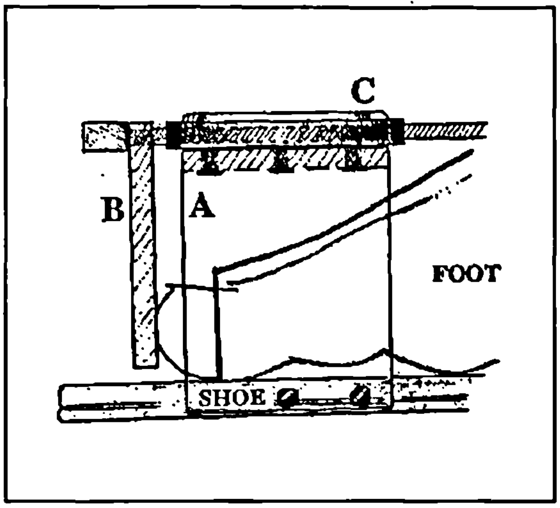

Figure 6.3: MEASURING DEVICE
A:FRAME, B:VERTICAL LOCATER,
C:MECHANICAL MEASURING METER

A window at the toe region was cut out back to expose approximately half of the big toe, which is about 228 mm (averaged size 4 subjects' foot length, see Chapter 4, Table 4.5(B)). The trial shoe still fits in the joint region and the tip of the toe is then exposed for all 5D subjects.

(2) Measuring device: The mechanical measuring device was designed by the researcher assisted by the Mechanical Engineering Section of Department of Medical Engineering & Physics, who also manufactured the device. It consists of three parts which are (A) frame, (B) vertical locater and (C) mechanical measuring meter (see **figure 6.3**).

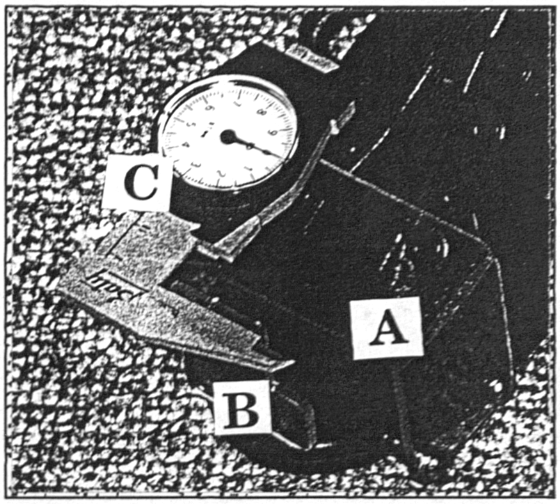

Figure 6.3: MEASURING DEVICE A:FRAME, B:VERTICAL LOCATER, C:MECHANICAL MEASURING METER

(3) Subjects selection: In this trial, 23 normal adult female subjects were selected of nominal size 5, within these volunteers, 5D01 to 5D10 are the same as in the *Shell shoe Fitting and Last & Fit Assessment Trials*, only one subject (5D03) was not available.

(4) Measurement: The extension of the foot length was measured in 3 different positions (ie. sitting, standing and walking positions) and with barefoot[6]. Care should be taken particularly, however, to ensure that these trialled feet can be fitted. Moreover, the topline and the backpart of the shoe are not allowed to slip forward. The measuring procedure is specified as follows

The weight-off measurements were taken with the subject seated and the foot resting against a fitting stool[7]. The weight-on measurements were taken with the subject standing and with weight on both feet evenly. The subject put on the trial shoes, stood up. And then the mechanical measuring meter was zeroed. The subject walked leisurely along the walkway (about 7.5 to 10 metres long), and the extension of measurement was then read and recorded.

[6] Lady's thin nylon stockings are allowed.

[7] A 30 cm height bench with sloped working plane which inclined at 30 degrees angle to the horizontal for measuring foot and fitting shoe.

6.4 Results and analysis

Table 6.1 presents the measured foot length in sitting (weight-off), standing (weight-on) and walking conditions. The measuring differences between these three different positions are also listed

(mm)	sitting	standing	Walking	d(on/off)	d(on/walk)	d(off/walk)
5D01	237	243	245.5	6.0	2.5	8.5
5D02	238	243	248.6	5.0	5.6	10.6
5D04	236	241	245.7	5.0	4.7	9.7
5D05	235	241	244.1	6.0	3.1	9.1
5D06	239	245	247.9	6.0	2.9	8.9
5D07	236	241	246.9	5.0	5.9	10.9
5D08	235	241	245.4	6.0	4.4	10.4
5D09	233	240	242.6	7.0	2.6	9.6
5D10	234	240	243.5	6.0	3.5	9.5
5D11	231	237	241.3	6.0	4.3	10.3
5D12	234	239	243.8	5.0	4.8	9.8
5D13	236	242	246.8	6.0	4.8	10.8
5D14	242	248	251.2	6.0	3.2	9.2
5D15	240	245	249.6	5.0	4.6	9.6
5D16	236	241	246.5	5.0	5.5	10.5
5D17	238	243	246.8	5.0	3.8	8.8
5D18	239	245	249.0	6.0	4.0	10.0
5D19	235	239	243.0	4.0	4.0	8.0
5D20	234	241	245.2	7.0	4.2	11.2
5D21	238	243	247.7	5.0	4.7	9.7
5D22	238	246	249.5	8.0	3.5	11.5
5D23	239	245	248.9	6.0	3.9	9.9
5D24	236	240	243.1	4.0	3.1	7.1
Average	**236.5**	**242.1**	**246.2**	**5.7 (SD=0.9)**	**4.1 (SD=0.9)**	**9.7 (SD=1.1)**

Table 6.1: THE RESULTS OF FOOT LENGTH MEASUREMENTS.

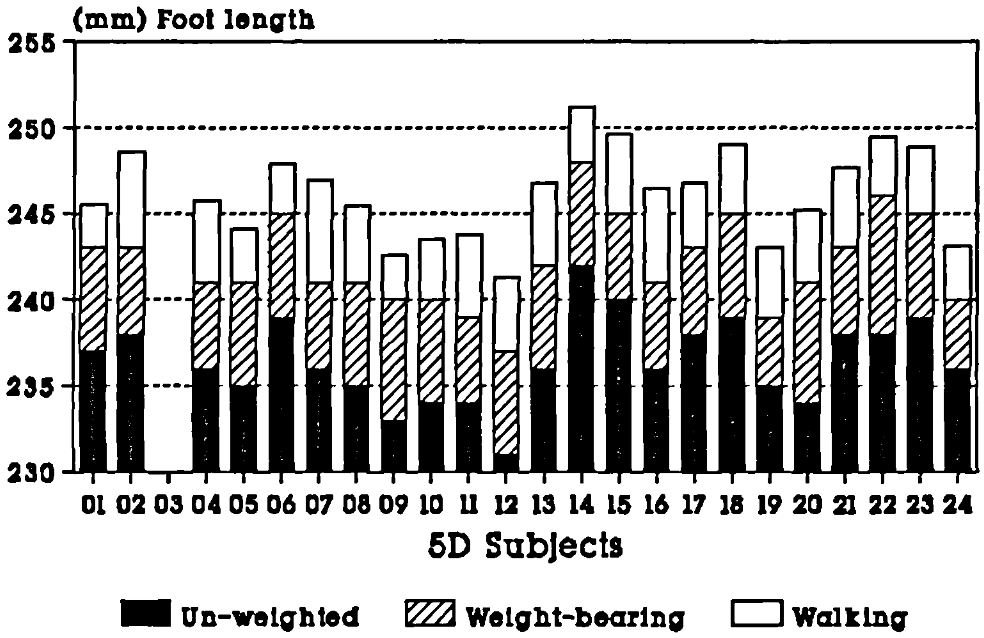

Figure 6.4: FOOT LENGTH UNDER UN-WEIGHTED, WEIGHT-BEARING AND WALKING CONDITIONS.

Figure 6.4 shows the detailed results of the foot length under un-weighted, weight-bearing and walking conditions. Anticipated subject 5D03 was not available at the time of this trial. The measurements of standing (in comparison with the sitting) and walking (in comparison with the standing) are illustrated in **figure 6.5** and **figure 6.6**, and one line each shows the assumed trend within their scattered data points *SP(x,y)*.

In **sitting/standing** condition, the regression equation of this assumed trend-line can be calculated as

$$y = x + 5.65$$

$$r = +0.9; \quad SP(x,y): 231 \le x \le 242, \ 237 \le y \le 248$$

This indicates that a positive correlation with 90% of variation between sitting (weight-off) and standing (weight-on) positions. The standard error of this correlation coefficient can be checked by *t-distribution*

$$t = r \times \sqrt{\frac{n-2}{1-r^2}} = 9.45$$

Entering the *t table* at *n-2* degrees of freedom (*DF= 21*)[8], it shows that at *t= 9.45*, the standard error probability (*P*) is much smaller than *0.1%*. This indicates that the correlation coefficient between sitting and standing measurements may be regarded as highly significant.

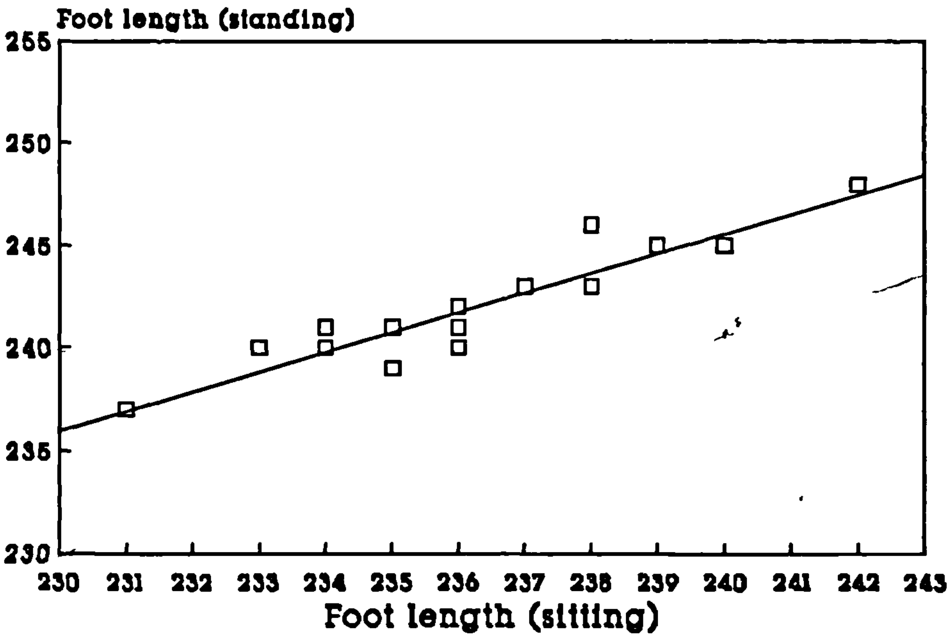

Figure 6.5: RELATIONSHIP BETWEEN SITTING & STANDING MEASURES.

In standing/walking condition, the regression equation of this trend-line for their relationship can also be calculated as

$$y = x + 4.07$$

$$r = +0.9; \quad SP(x,y): 237 \le x \le 248, \; 241 \le y \le 252$$

[8] The *DF= n-2* shows that two degrees of freedom have been lost, because two data were estimated to calculate the linear regression. It also indicates that this statistic value has a *t*-distribution with *n*-2 degrees of freedom, provided that the variables are **bivariate normal.**

The standard error probability of this correlation coefficient is $P < 0.1\%$ ($DF = 21$, $t = 9.45$). This indicates that the correlation coefficient between standing and walking measurements may also be regarded as highly significant. As well as sitting/standing, the relationship between standing and walking is found highly inter-dependent and linearity. This means that within the range of each scattered data points $SP(x,y)$, for any measured un-weighted foot length should be 5.7 mm shorter than that of weight-bearing on average. Similarly, there should be an averaged 4.1 mm between weight-bearing and walking foot length. This regression line is however only based on feet around size 5, and it should be noted that it may not be applied outside of this range.

Figure 6.7 shows the relationship between the weight-bearing (on/off) extension and the toe extension (23 subjects), and an assumed trend-line within those scattered data points $SP(x,y)$. The regression equation of this trend-line can be calculated as

$$y = -0.39x + 6.26$$

$$r = -0.38; \quad SP(x,y): 4 \leq x \leq 8, \ 2 \leq y \leq 6$$

This negative correlation of $r = -0.38$ ($DF = 21$, $t = 1.9$) indicates a non-significant correlation ($5\% < P < 10\%$) which means that the compared results also indicate that there are more individual than common factors between weight-bearing extension and toe extension.

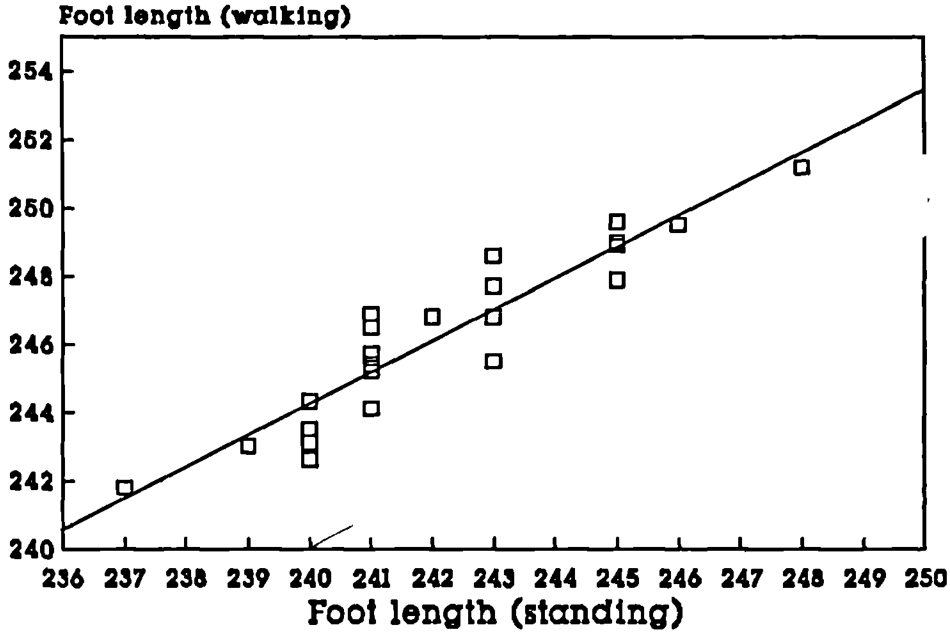

Figure 6.6: RELATIONSHIP BETWEEN STANDING & WALKING MEASURES.

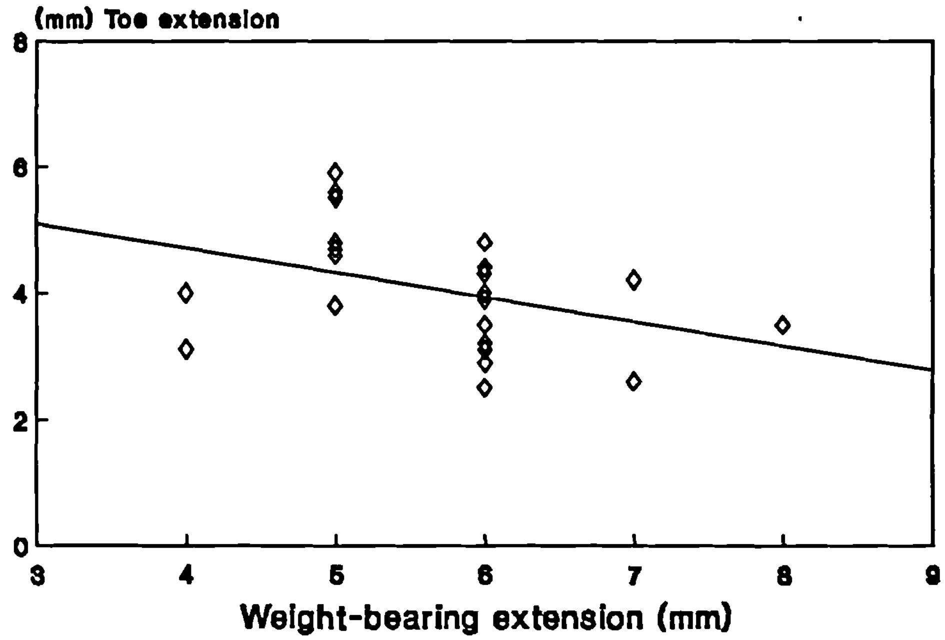

Figure 6.7: THE WEIGHT-BEARING (ON/OFF) vs. TOE EXTENSION.

6.5 Discussion

6.5.1 Weight-bearing extension

The weight-bearing extension is the first key factor which determines the total foot extension. During standing, the longitudinal arches (ie. medial and lateral arches) and the anterior arch of the foot are of importance in helping to keep the whole foot in balance and serve as a major shock absorber. The primary cause of foot extension is the flattening of the longitudinal arches in length and the flattening of the anterior arch in width.

Figure 6.8 shows the weight-bearing extension (a+b) at the region of medial arch where the weight-on position of the bone structure is illustrated by a solid line and the weight-off by a dotted line. The weight of the body, transmitted by the lower limb, is applied through the ankle to both the forepart and backpart of the foot. In the case of forefoot pronation on weight-bearing, the medial arch will lengthen more than the lateral arch does, because the lateral arch is very low and has little capacity to lower.

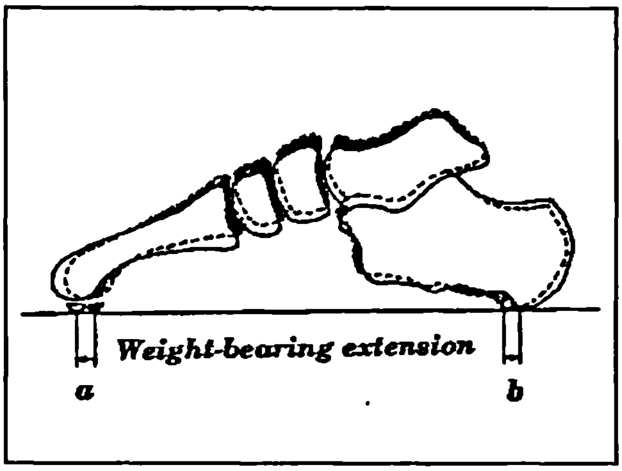

Figure 6.8: THE WEIGHT-BEARING EXTENSION **a+b** AT THE REGION OF MEDIAL ARCH WHICH CONSISTS OF FIVE BONES.

Figure 6.9 explains that the weight-bearing extension of **a+b** and its related weight-on and weight-off positions. In this trial, an averaged weight-bearing extension of **a+b** = **5.7 mm** (*SD= 0.9, n= 23*) is measured. This measurement cannot be assumed as the total foot extension because it consists of weight-bearing extension, toe extension and the soft tissue spread.

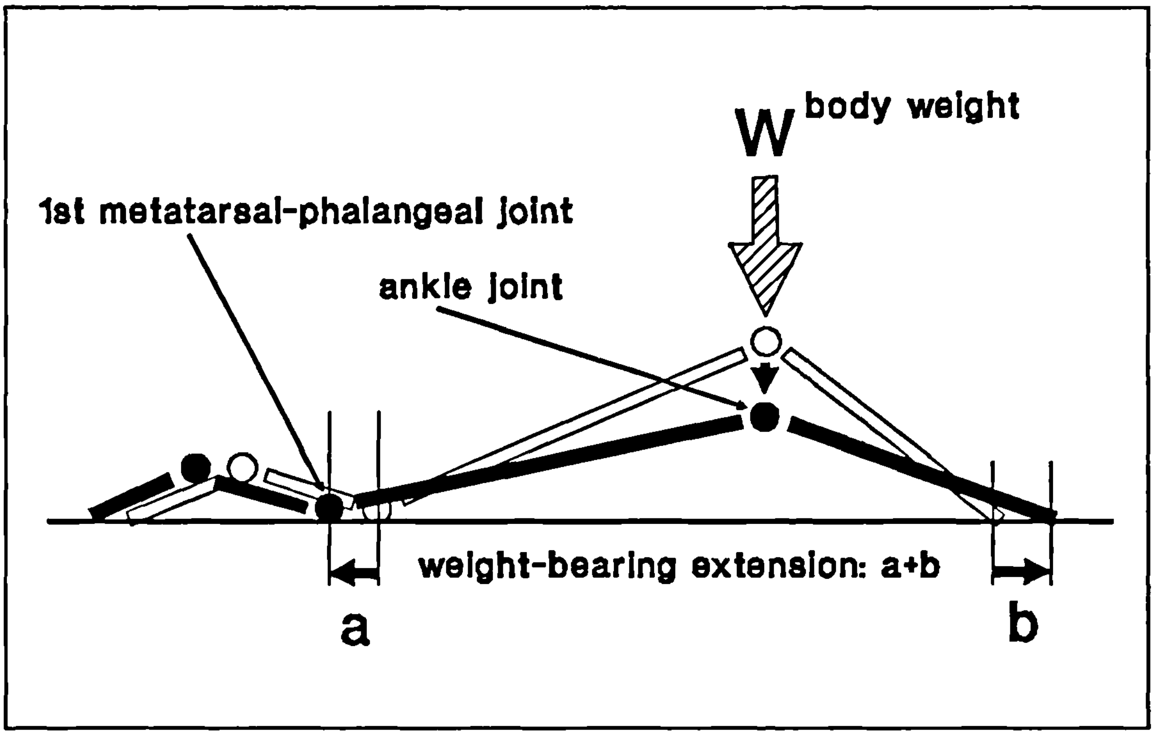

Figure 6.9: THE WEIGHT-BEARING EXTENSION (a+b) AND ITS RELATED WEIGHT-ON AND WEIGHT-OFF POSITIONS.

6.5.2 Toe extension

The toe extension is the other important key factor which determines the total foot extension. The morphologic type of the foot plays an important and different role in the development of the toe extensions. According to **Kapandji (1987)**, there are three types of foot:

(1) the **Egyptian foot**, as observed on status of the Pharaohs, with the big toe being the longest while the others decrease in length successively;

(2) the **Greek foot** (also called **Roman foot**), as seen in classical Greek (or Roman) statues, the 2nd toe is the longest one and followed by the big toe and 3rd toe;

(3) The **Polynesian foot**, or square foot, with the first three toes being of equal length.

In the case of the **big toe**, which is normally the longest[9] toe of the foot, while the foot rises to the push-off position, the proximal end of the 1st metatarsal swings upwards and the body weight thrust moves forward onto the region of the 1st metatarsal-phalangeal joint. When pressure is exerted downwards from the body weight, the sesamoids under the 1st metatarsal head serve as a stable "ball-bearing" which prevents the 1st metatarsal head from gliding. This is a pure movement of rotation around an axis within the 1st metatarsal-head[10] (see **figure 6.10**).

Although the sesamoids improve the rotation and balance when walking, the distance between the notional axis within the 1st metatarsal-head and the sesamoids base may produce a degree of rotation ie. the base of sesamoids act as the rotational centre. Therefore, the rotated metatarsal-phalangeal joint is then pushed forwards (see **figure 6.10** for details of toe extension, **c**, at the big toe, where **1** is shown as the mid-stance position, **2** as the push-off position).

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[9] According to **Lake (1945)**, there are 69% of population with the big toe being the longest.

[10] The normal metatarsal-phalangeal joint has an arc of flexion-extension of about 90 degrees; in most cases, the flexion is about 10 degrees and the extension about 80 degrees (Helfet et al, 1980).

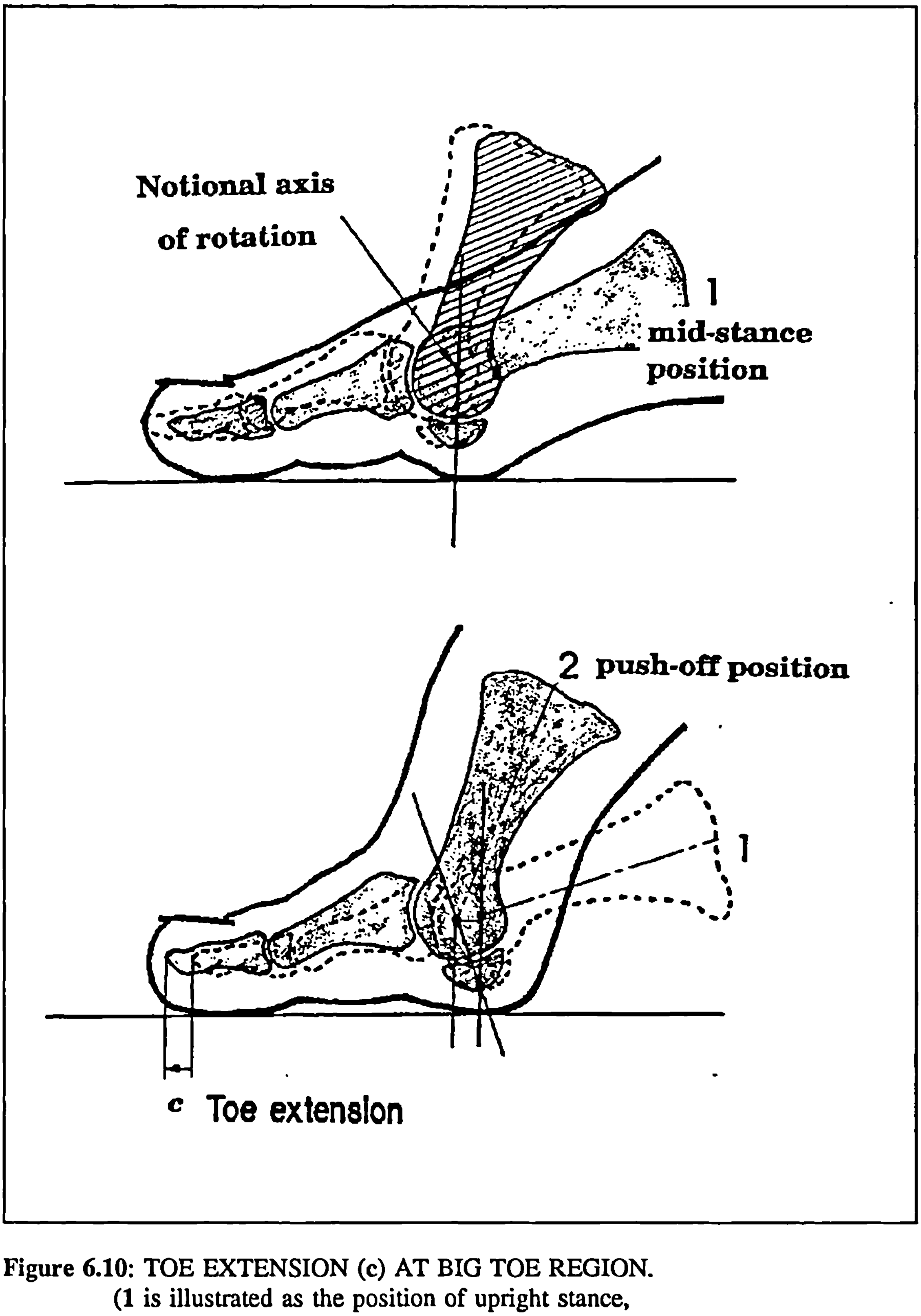

Figure 6.10: TOE EXTENSION (c) AT BIG TOE REGION.
(1 is illustrated as the position of upright stance,
2 as the push-off position)

In the case of the **2nd toe** or the other lesser toe, which is assumed as the longest toe of the foot, however, no such (sesamoids) provision exists and these lesser metatarsal-heads therefore act in a rolling and gliding movement. During walking, the lesser metatarsals swing upwards, the tips of the toes are held in opposition to the ground or support surface of the shoe instinctively by the muscle action and so the toes buckle with the metatarsal-heads being pulled forward. While the body weight is transferred to the forefoot region, the proximal inter-phalangeal joints are then flattened and the toes are pushed forward. The extension also depends on which metatarsals are held in frictional contact[11] with the ground by the body weight. **Figure 6.11** explains the toe extension, **d**, at the 2nd toe (or other lesser toe) region, where **1** represents the foot flat or mid-stance position, **2** as the early push-off position and **3** as the position of the late push-off or early toe-off).

The difference (**c** or **d**) between the standing and walking measurements ranges from 2.5 mm to 5.9 mm, the average being **4.1 mm** (*SD= 0.9, n= 23*). From this point of view, the averaged total foot extension (walking extension), ie. the difference between walking and sitting measurements, can be calculated as **9.7 mm** (*SD= 1.1, n= 23*) with the range of 7.1 mm to 11.5 mm.

In-shoe foot length measured from these 5D subjects between weight-off and weight-on is averaged 5.7 mm (range from 4 to 8 mm, *n= 23*). This seems **LOW** when compared to averaged 8.8 mm (range from 2 to 12 mm, *n= 20*) of barefoot (**Shereff et al, 1990**) and about 20 mm (*SD= 4.1, n= 6*) of averaged 1st metatarsal-heads location moving forward (**Lord et al, 1992**). Nevertheless, compared to SATRA's suggested toe room allowance of 5 mm for female adults (**Larcombe, 1990**), the averaged 9.7 mm of this trial seems **HIGH**. These indicate that the variables depend on the different foot conditions such as foot rigidity, foot bio-mechanics and foot fitted in shoe.

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[11] It is implied that the sub-cutaneous soft tissue pad and skin can affect the foot extension through frictional contact (Lake, 1945).

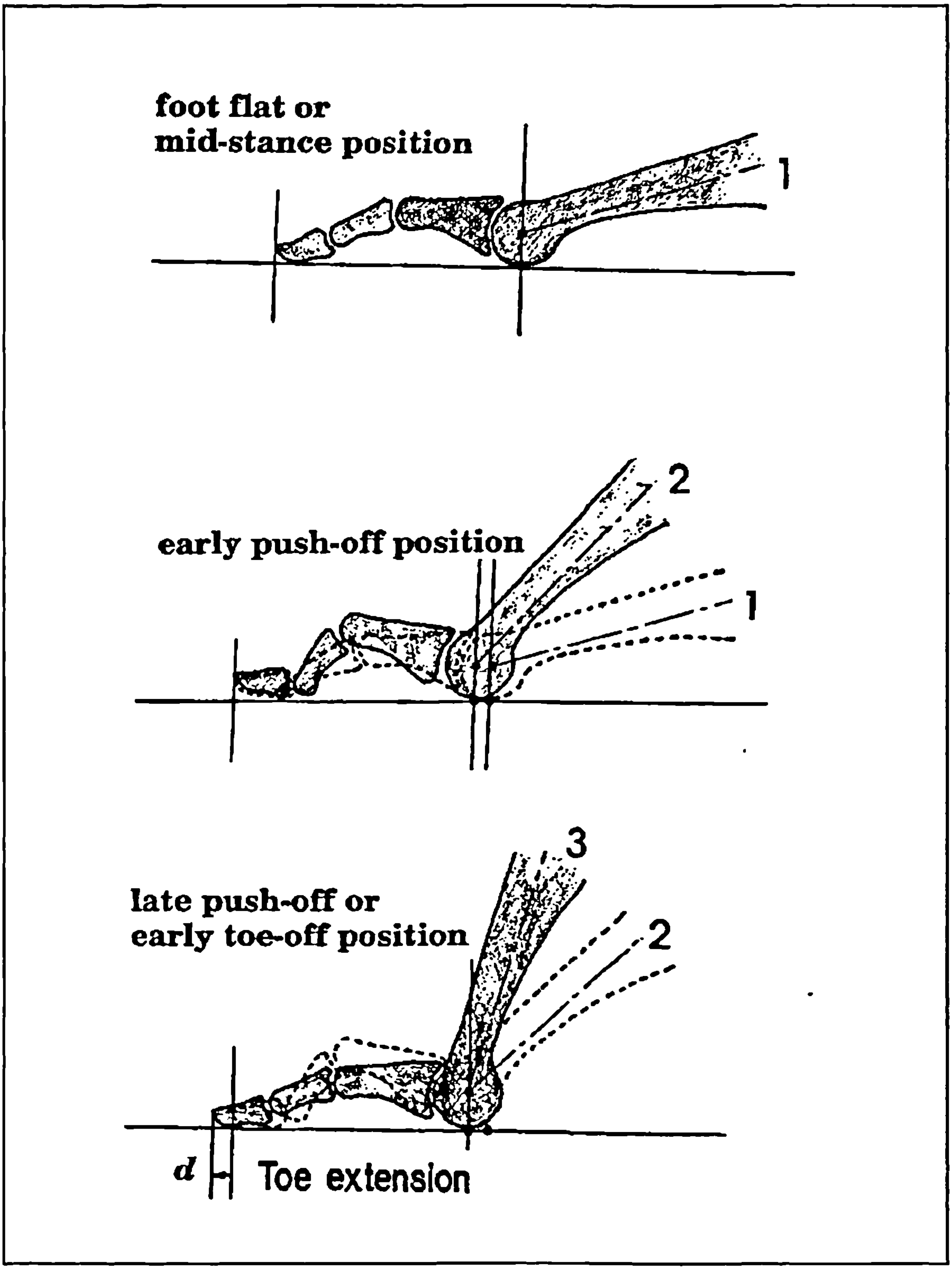


Figure 6.11: TOE EXTENSION (d) AT THE LONGEST 2nd TOE
(OR OTHER LESSER TOE) REGION.

6.6 Conclusions

A special in-shoe measuring device was successfully developed for taking the foot length extension from weight-off (sitting) through weight-on (standing) to walking. It is the first time that total foot extension (walking extension) has been measured from inside the shoe. By comparing the measured results, the total foot extension can be separated into two independent extensions ie. weight-bearing and toe extension. This study also indicates that these two effective foot extensions have more differences than similarities. The weight-bearing extension is due to the arch flattening but the toe extension is due to the mechanical movement of forefoot.

The normative results (data) of this trial are important and useful for applying to the orthopaedic shoe last making and for comparison with the patient groups. From this point of view, a further, more detailed study with a greater number of subjects and a wider range of sizes (eg. size/4, size/6 etc.) are required to verify its accuracy. However, this inside shoe measuring device is not allowed to measure overall foot length which is taken by size stick. The study described is a first step towards understanding the significance of the inside shoe foot measurement in walking.

CHAPTER 7
GENERAL DISCUSSION

7.1 Measurement accuracy

Observer tests:

In chapter 4, both the intra-observer and inter-observer tests were undertaken to improve the reliability and the consistency of the measures. Although only one subject was used for the tests, the measurements are taken from 38 points in both right and left feet, ie. 12 points of length, 12 points of girth and 14 points of height measurement.

In **intra-observer tests**, the discrepancy of measurements averaged 2.0 mm (*SD= 1.4, n= 38*), consisting of an average 2.0 mm (*SD= 0.8, n= 12*) in length, 2.8 mm (*SD= 1.9, n= 12*) in girth and 1.4 mm (*SD= 0.9, n= 14*) in height measurement. The greatest discrepancy of 6 mm at the instep girth measuring point indicates that it is not very easy for a junior operator to position the metatarsal-cuneiform joint (instep point) correctly. This problem was improved by marking the measuring positions.

Learning from the experience of intra-observer tests, before the **inter-observer tests** were undertaken, some reference points were determined and marked on the subject's feet to ensure the same location of measures. The discrepancy of measurements between the two operators averaged 2.5 mm (*SD= 2.0, n= 38*), consisting of an average 1.8 mm (*SD= 1.0, n= 12*) in length, 3.5 mm (*SD= 2.9, n= 12*) in girth and 2.3 mm (*SD= 1.4, n= 14*) in height measurement. There was an extraordinary discrepancy of 10 mm (left foot) and 8 mm (right foot) at the long heel girth measuring point, because it is difficult to place the measuring tape stably and correctly. This problem can be improved by the use of a narrower measuring tape. The comparison of these measurements indicates that the senior shoe-fitter (JT) tends to use the measuring instruments tighter than the junior (RC).

Unlike other solid objects, the foot is covered by skin and tissues which are soft, flexible and able to be compressed and moved to a limited degree. It also contains the endings of many sensory nerves which can be stimulated by pressure etc., and a limited degree of pressure can be tolerable. For this reason, an additional test using measuring instruments loosely and tightly was required to identify the differences. In the loose/tight tests, the discrepancy averaged 0.9 mm (*SD= 1.3, n= 12*) in length, 11.9 mm (*SD= 2.5, n= 12*) in girth and 2.5 mm (*SD= 1.3, n= 14*) in height measurements. Obviously, the measurements taken from the girth region show a much greater difference than the other measurements. This indicates that the softer the tissue, the greater is the discrepancy.

Comparison between machine and manual measures:

From the results of cross-sectional data (see *Chapter 3, Section 3.4.2: tables 3.7 to 3.10*), some cross-sections of foot model and two lasts were also measured using manual tape by the researcher. The cross-sections were measured at the position of 1st metatarsal-head (*z= -170 mm*), 5th metatarsal-head (*z= -155 mm*) and instep points (*z= -140 mm*) and consisted of girth, depth and width measurements. In the case of width measurements, the additional throat (*z= -90 mm*), medial malleolus (*z= -55 mm*) and lateral malleolus points (*z= -40 mm*) were also taken. **Table 7.1** shows the comparison between machine digitised data and manual measurements. The negative data indicate that the manual measurements are smaller than the machine digitised ones.

The discrepancy of measurements between the two measurement techniques averaged 0.2 mm (*n= 36*) ranging from 2.8 mm smaller to 2.2 mm bigger, consisting of an average 0.5 mm (range from -1.2 to 2.2 mm, *n= 12*) in foot, 0.1 mm (range from -2.8 to 1.4 mm, *n= 12*) in last-H6028S and -0.1 mm (range from -2.1 to 1.5 mm, *n= 12*) in last-H6028 measurement. This indicates that by careful use of the modified measuring tape (2 mm wide), the same level of accuracy can be achieved as with the automatic digitiser. However, in many measurements, the machine digitised method remains preferable to the manual for its speed, location, and accuracy, etc.

unit: mm		FOOT	H6028S	H6028	Average
GIRTH	-170	1.6	0.8	-0.3	0.7
	-155	1.1	0.6	-2.1	-0.1
	-140	-1.1	1.4	1.2	0.5
DEPTH	-170	-1.2	-0.7	-0.9	-0.9
	-155	0.7	-2.8	-1.2	-1.1
	-140	0.1	-0.5	-0.3	-0.2
WIDTH	-170	0.6	0.0	0.1	0.2
	-155	0.1	0.5	0.0	0.2
	-140	-0.3	0.5	-0.1	0.0
	-90	0.7	0.5	1.5	0.9
	-55	1.8	0.7	0.5	1.0
	-40	2.2	0.5	1.0	1.2
AVERAGE		0.5	0.1	-0.1	0.2
TOTAL AVERAGE		0.2 mm			
TOTAL RANGE		from -2.8 mm to 2.2 mm			

Table 7.1: COMPARISON BETWEEN MACHINE DIGITISED DATA AND MANUAL MEASUREMENTS.

Heel to ball and heel to toe:

Although in the volume shoe trade the heel to ball measurement is not adopted widely, however, it would be useful for orthopaedic patients who have deformed or amputated toes. It is difficult to check accurately, without a special measuring instrument, such as Brannock device. In this research, a re-scaled (metric scale) Brannock device was used to improve the heel to ball measurement.

The measurement of heel to ball can affect the size and fitting of the shoe as much as that of heel to toe. The results of shell shoe fitting in chapter 4 shows that for acceptable volume shoes, the averaged heel to ball measurement is 10 mm shorter than the foot. A parallel case study into orthopaedic footwear(**Lord, 1992b**)also points out that in weight-off position, the ball of the foot about 5 mm (*n*= *100*) forward of the last ball on average. When the foot is fully weighted, there should be a further extension of the foot, which would move the foot ball further forward. The foot should not be compressed, especially in the joint girth region. Although the softness and flexibility of the shoe upper allow a degree of accommodation for foot movement forward, insufficient heel to ball length in the shoe may push the ball joint of the foot too far forward resulting in compression on the foot and producing discomfort or some chronic foot problems.

Furthermore, measured on the 5D subjects (see *Chapter 5*), the difference of medial heel to ball length between left and right foot of the same subject (23 pairs) ranges from 0 to 7 mm, average 0.4 mm in weight-off position and in weight-on position from 0 to 8 mm, average 0.4 mm. The range of medial heel to ball measurement (46 feet) was 14 mm (weight-off), and 15 mm (weight-on). The difference of medial heel to ball between weight-off and weight-on averaged 1.8 mm. There is a small averaged discrepancy of 2.1 mm (weight-off) and 0.3 mm (weight-on) between the standard model last and the foot, the foot being smaller than the last in both position.

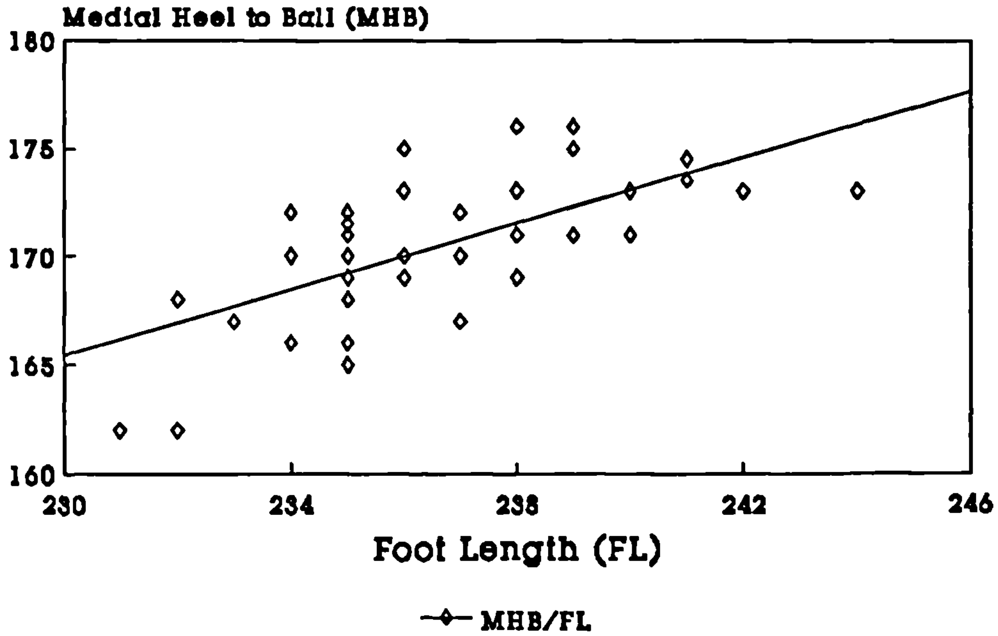


Figure 7.1: MEDIAL HEEL TO BALL (MHB) vs. FOOT LENGTH (FL)

Figure 7.1 shows the relationship between medial heel to ball length and overall foot length of 46 feet in weight-off position. The regression line illustrates the trend within those scattered data points *SP(x,y)*. The regression equation of this trend-line shows a significant correlation coefficient as

$$y = 0.76x - 10.38 \qquad (weight\text{-}off)$$

$$r = +0.66; \quad SP(x,y): 231 \le x \le 244, \ 162 \le y \le 176$$

$$P < 0.1\% \qquad (t = 5.77, \quad DF = 44)$$

Similarly, in the case of weight-on position, the regression equation and its correlation coefficient can also be calculated as

$$y = 0.76x - 13.46 \qquad (weight\text{-}on)$$

$$r = +0.71; \quad SP(x,y): 235 \le x \le 251, \ 162 \le y \le 177$$

$$P < 0.1\% \qquad (t = 6.59, \quad DF = 44)$$

From **size 5** data, the average relationship exists that both highly significant correlations have implications for the heel to ball and heel to toe measurements, ie. the heel to ball length (*HB*) is predictable from the measurement of heel to toe length (*HT*). It can be calculated as

$$HB = 0.76 \times HT + c$$

$$c = -10.4\,mm \ (weight\text{-}off), \qquad c = -13.5\,mm \ (weight\text{-}on)$$

Since **size 5** last is used as the standard model, then this proportion of **76%** would be held in grading and would be applied to the whole volume range.

7.2 Sizing of shoes

Nominal size vs. sizing system:

All the trialled female subjects in each experiment are nominal size 5D with a range of 231 to 242 mm in foot length averaged 236.5 mm. According to SATRA's guideline (**Browne, 1981**), an average 237 mm, ranging from 233 to 241 mm is suggested for the UK women's population of size 5 standard foot length. However, there will inevitably be some of those nominal size 5 subjects whose foot length is **shorter** or **longer** than the standard size 5 and would appear to be distributed by virtue of foot length into the suggested standard size 4 (225 to 233 mm) or standard size 6 (242 to 250 mm). It is probable within the nominal size 5 group that the shorter feet are accompanied by wider joint girth (width). Conversely, the longer feet are by narrower joint girth (width). The results in chapter 5 support this notion (see *table 5.4(A) & 5.4(C)*), eg. the subject-5D12 has shorter foot length with wider girth and the subject-5D18 has longer foot length with narrower girth. This is the problem with the existing sizing system based on measurements of one dimension of foot length, providing a single girth (width) fitting.

Shoe sizes can be easily re-marked in the shoe shop or the fitting department. As long as shoes are fitting well, the shoe shop will correct these sizing faults by selling (or trialling) either larger or smaller sizes. Therefore, correct sizing of a shoe is less important than having a well fitting shape, eg. if a sized **5** shoe is too small for a nominal size **5** foot but fits very well on sized **4** foot, then the mark of the shoe/last can be changed to size **4** but this does not change its dimension. This solution, because it copes only with the symptoms, will produce new sizing problem in volume shoe trade. For example, if a series of shoe sizes runs from size **3 to 8**, it could be found that, after marking down the sizes, there are no size **8** shoes, ie. the new range would be from size **2 to 7**.

In the case of bespoke orthopaedic footwear, this problem is less relevant because orthopaedic footwear is made to suit the feet of a particular patient and re-marking sizes is not allowed. Even with ready made orthopaedic shoes, the selected size should be correct the first time with adjustable cushion supports. The sizing problem can be alleviated by considering an **"effective length"** measurement.

Foot length and shoe length:

Based on the unpublished **C&J Clarks Fitting Manual** , an **"effective length"** is defined as a special length within a **SHOE** which allows an average **FOOT** to function normally. It includes not only the factor of overall **length**, but also the effect the factors of **shape, depth, width**. The effective length is shorter than overall shoe/last length but longer than the length of the average foot which fits the shoe. Firstly, the effective length of a shoe depends on its style of forepart shape, particularly the toe shape. Variation in toe shape patterns makes a difference to shoe-fit and the length required at the toe region. For example, in the case of an extreme pointed toe shoe and a rounded toe shoe with the same overall shoe/last length, the effective length of the pointed-toe shoe would be much **shorter** than that of rounded toe shoe. Moreover, when assessing shoe fit, the effective length can also be affected by the depth and width factors. For example, with shoes of the same length and shape but of extra depth and width, the effective length would be greater than that of normal depth and width shoes.

The toes should have sufficient space to move freely. In <u>chapter 6</u>, an average of 9.7 mm (*SD= 1.1, n= 23*) is calculated. However, as a minimum toe room allowance, this averaged 9.7 mm would be insufficient and too little to fit most of the subjects ie. 12 of the 23 subjects (about 52%). If an extra standard deviation (+1SD) of 1.1 mm is added, the gap between foot toe-tip and shoe toe-end is 10.8 mm which can fit 20 subjects (about 87% of population). In this trial, the maximum total foot extension of 11.5 mm for all subjects was found, which is within +2SD (ie. under 11.9 mm), this can be considered as a minimum toe room allowance of the last, because this allows sufficient room to conform to overall foot length during walking.

As the considerations of effective length discussed earlier this section, however, the length of toe room allowance plus overall foot length is not equal to the overall shoe/last length. It is for reference only as a minimum effective length requirement for basic last model design and shoe-fit assessment, an extra length being needed to accommodate those special fashion designed shoe styles such as a shallow, pointed and receding shaped toe.

7.3 Shoe fitting

Shell shoe fitting technique:

In this research, two different materials were used for the shell shoe uppers. One is 2000 micron PVC sheet which is soft and transparent (see *Chapter 4*), the other is 4000 micron EVA sheet which is soft but non-transparent (see *Chapter 5*). Although both of them are useful and successful, it is of interest to note the differences between these two upper materials. During the trial, the following observations were made

(1) Both materials are soft and flexible enough to permit walking.

(2) In the case of the surface property, EVA is much closer to leather than PVC. The PVC shell shoe is too smooth to grasp the foot which may cause a feeling of looseness and influence the fitting (eg. at the backpart topline, heel curve).

(3) The PVC has the strength of leather, whereas EVA shell shoe requires special reinforcement with fabric tape at topline, vamp and joint region to prevent it from breaking during walking trials.

(4) The finished PVC shell shoes felt harder to the subjects than the EVA shells and leather shoes.

(5) Although the PVC shells retained their last shapes, in comparison with the real shoes, PVC shells were found to be bigger around the top of the backpart and the heel curve and felt looser than the shoes. However, this may have resulted from lack of lacing or fastening at the forepart upper of the shells, a problem which was solved by making modifications ie. by attaching velcro to the facing or using laces.

(6) In shell shoe making, the PVC shells were more difficult to pull-off the last than the leather shoes or the EVA shells. Special care needed to be taken to prevent the topline from becoming distorted.

(7) Although the EVA shells were not as tight as the leather shoes, they were better than the PVC shells. This might be the result of material shrinkage. However it would be necessary to follow this up with the further research.

(8) The EVA shells can provide a better fitting assessment in the areas where PVC shells are deficient (ie. backpart heel region).

(9) The transparent property is the greatest advantage of the PVC shell when assessing the fit.

In summary, some recommendations can be made. In the case of volume shoe trade, the EVA shells might be better than the PVC shells because of their flexibility in walking trials. On the other hand, in the orthopaedic trade the PVC shells might be more useful, because the emphasis is on achieving an accurate shape and minimum pressure. Of course, it does not follow that the PVC shells are useless in volume shoe fitting or that the EVA shells are unsuitable in orthopaedic footwear fitting. A combination in use of these two materials in shell shoe fitting could achieve the best results.

7.4 Last allowances

Relationship between cross-sections of foot shoe and last:

The cross-sectional shape of the shoe last and hence the unworn shoe is completely different from that of the foot. The cross-section of the shoe is much narrower and deeper than that of the barefoot, and the cross-sectional area of shoe is greater than that of the foot (see *Chapter 3, Section 3.5*). When the shoe is worn under the well fitted condition, the shape and circumference of shoe and foot should be matched at the ball joint[1] region, ie. the shape and girth of outer material (shoe) and the inner material (foot) should be conformed. Therefore, the cross-sectional areas and circumferences should in theory be the same.

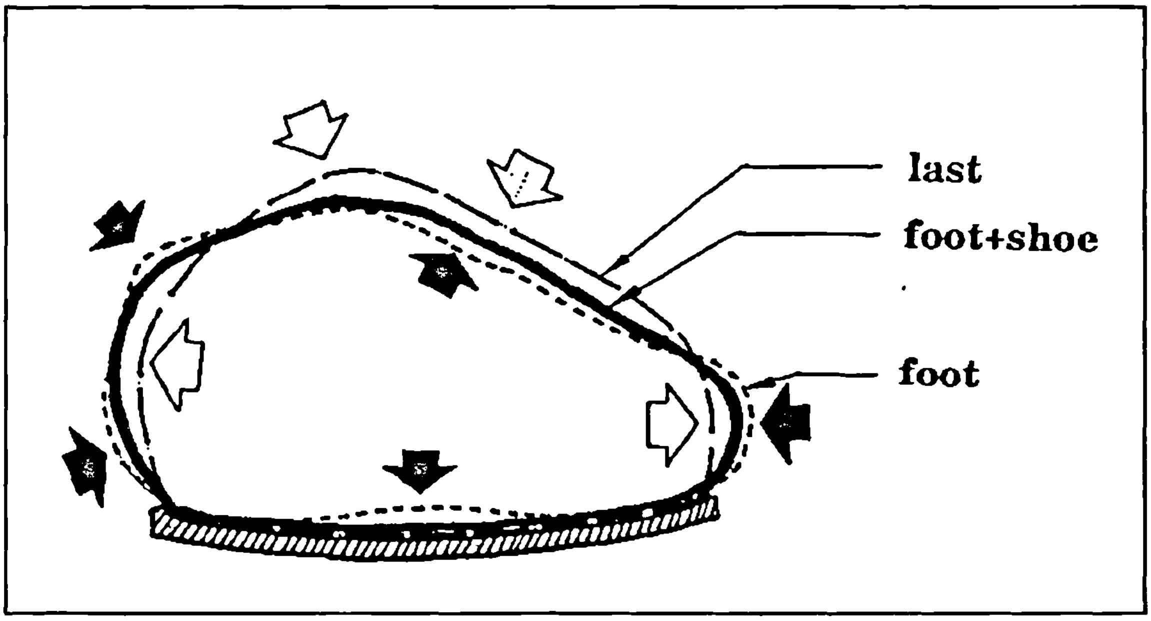


Figure 7.2: UNDER THE CONDITION OF GOOD-FIT, THE FOOT & SHOE NEED TO BE MOULDED TO ACHIEVE THEIR NEW BALANCED SHAPE. (ie. the shoe is flattened, and the foot will be compressed)

In order to achieve this fit, both the foot and shoe need to be moulded to achieve a new balanced shape, ie. the shoe will be flattened and the foot will be deformed into a rounder shape. **Figure 7.2** illustrates their cross-sectional contours; the foot is shown

[1] In the positions of hindfoot, midfoot and toe regions, their cross-sectional shapes are different because the stiffener and cushion support materials in the backpart and toe room allowance in the forepart need to be considered.

as a dotted line, the last (unworn shoe) as a segmental line and their balanced shape (foot+shoe) as a bold continuous line.

Relationship between the girths of the weight-on/off foot and shoe last:

Figure 7.3 shows the relationship of joint girth measurements between best-fit last (*OK*) and subjects' feet in both weight-on and weight-off conditions (see *Chapter 5, table 5.8*).

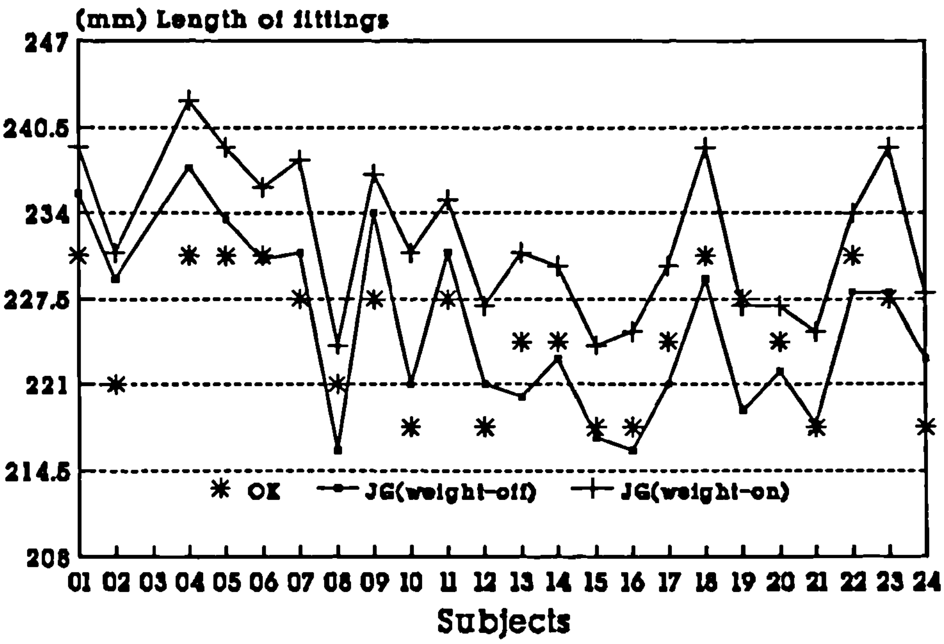


Figure 7.3: THE DIFFERENCES BETWEEN *OK* MODEL LAST & FOOT MEASUREMENTS (BOTH WEIGHT-ON & WEIGHT-OFF).

The averaged weight-off joint girth measurement (225.9 mm) is 1.2 mm (*n= 46*) greater than that of the best-fit last (averaged 224.7 mm); the averaged weight-on joint girth measurement (231.4 mm) is 6.7 mm (*n= 46*) greater. When the condition changes from weight-off to weight-on, there is an average increase of **5.5 mm** in joint girth measurement, which is due to foot deformation ie. the soft tissues and skeleton have been deformed, and the skin has stretched to a limited extent. The upper materials (eg. leather) of the shoe, on the other hand, are virtually inextensible, the girth remaining the same as the last (or unworn shoe condition). So, when the condition changes from weight-off to weight-on, the cross-sectional circumference of the foot increases an averaged **5.5 mm** but the cross-sectional circumference of the shoe remains the same. Moreover, the cross-sectional area of the foot remains the same during condition changes but the cross-sectional area of the shoe decreases by about **140 sq.mm.** (see *Chapter 3, Section 3.5*). Therefore the shoe feels tighter on the foot in the weight-on position.

The measured results also show that the joint girth measurement of the last is about the same as that of the weight-off foot, and about one full fitting **smaller** than that of the weight-on foot. Therefore, in shoe last design for female volume shoes, to take the joint girth measurements in the weight-off position might be more reasonable, because a difference of **5.5 mm** in tightness can be covered from the averaged **5.5 mm** of the acceptable fitting tolerance (see *Chapter 5, Section 5.5*), whereas, if joint girth measurements are taken in the weight-on position this might be too loose to be acceptable. In the case of orthopaedics, although **British Standard 5943 (1980)** suggests that the foot measurements are taken with the patient seated[2], many orthopaedic footwear manufacturers in the UK usually add an extra girth allowance[3] (about **6 mm**, see *Chapter 3, Section 3.3, Table 3.1*) onto the last when making it, this allowance being very close to the **5.5 mm** difference between weight-on and weight-off.

The problem with the existing measuring system is that the orthotist (or orthopaedic shoe-fitter) takes these measurements with the patient seated and the orthopaedic footwear manufacturer adds a girth allowance. When the shoe/last has been made, it is sent to the orthotist/patient for fit assessment in weight-on (walking) positions. If these prove unsatisfactory, the shoes then have to be returned to re-work. From this point of view, it makes the whole process very complicated. It might therefore be better if weight-on rather than semi-weightbearing position was used for orthopaedic shoe/last design and manufacturing.

---

[2] Sometimes the seated patient is asked to press the knees downwards. This puts partial weight on the feet, giving a **semi-weightbearing** condition, between weight-on and weight-off.

[3] This girth allowance has been worked out from experiences gained over many years (see *Chapter 3, Section 3.3, Table 3.1*).

Acceptable fitting boundaries for joint girth:

Looking at fitting allowances in traditional measurements, SATRA footwear technology centre has recently been engaged in a similar field of research, which is a project to explore more about the relationship between the foot and the last (**Browne, 1993**). Although their path and that of the researcher runs parallel, this research (in chapter 5) has been carried out independently.

A selected shoe/last with the joint girth of **219 mm** plus two graded shoes/lasts (6 mm up/down) were used as the fixed best-fit joint girth in SATRA's fitting trials. An averaged tolerable fitting range of joint girth was suggested as 6 mm for both loose and tight fitting boundaries, which was acceptable to **65%** of the population (*n= 16 pairs*). In chapter 5, on the other hand, the best-fit joint girth was not fixed. It was determined for each fitted individual foot from the available range. An averaged best-fit joint girth was found to be **224.7 mm** (*n= 23 pairs*). **43.5%** of population accepted the **+1** width fitting boundary (about 6.5 mm looser) and **60.9%** found **-1** width fitting boundary (6.5 mm tighter) acceptable. The acceptable limit of tolerance might reasonably be expected to be different between tightness and looseness. For example most of the subjects found the looser rather than the tighter shoes acceptable on the first wearing but finally they selected the tighter one. This is because customers are used to expecting shoes (especially leather shoes) to "**give**", whereas shoes which are bought with fitted or acceptable loose, soon become too loose to grip the feet. This then would depend critically on what instructions were given to the subjects ie. which shoes (1) **would you buy** or (2) **fit you now**. In both trials, the (1) instruction was given to the subjects. According to SATRA's results, there is no difference between tight and loose fitting boundaries. This research in chapter 5, however showed that the acceptable limit of tolerance is different for tightness and looseness. Based on the trialled fitting results, of the 23 subjects, 9 subjects (39%) found their acceptable tight/loose fitting boundary to be the same, 5 subjects (22%) preferred looser fitting than tighter and 9 subjects (39%) the reverse. In addition, an average difference of acceptable loose-fitting boundary (4.7 mm) and tight-fitting boundary (5.5 mm) were calculated (see *Chapter 5, Table 5.7*) at the joint girth for the nominal 5D subjects.

Although both results of acceptable fitting boundary are very close, the "best-fit" joint girth of these two trials is quite different. There is **5.7 mm** discrepancy between SATRA (219 mm) and this research (224.7 mm). This is due to the **use of different trial shoes**. This difference is mainly in the style of the topline (ie. whether high or low cut; see **figure 7.4**).

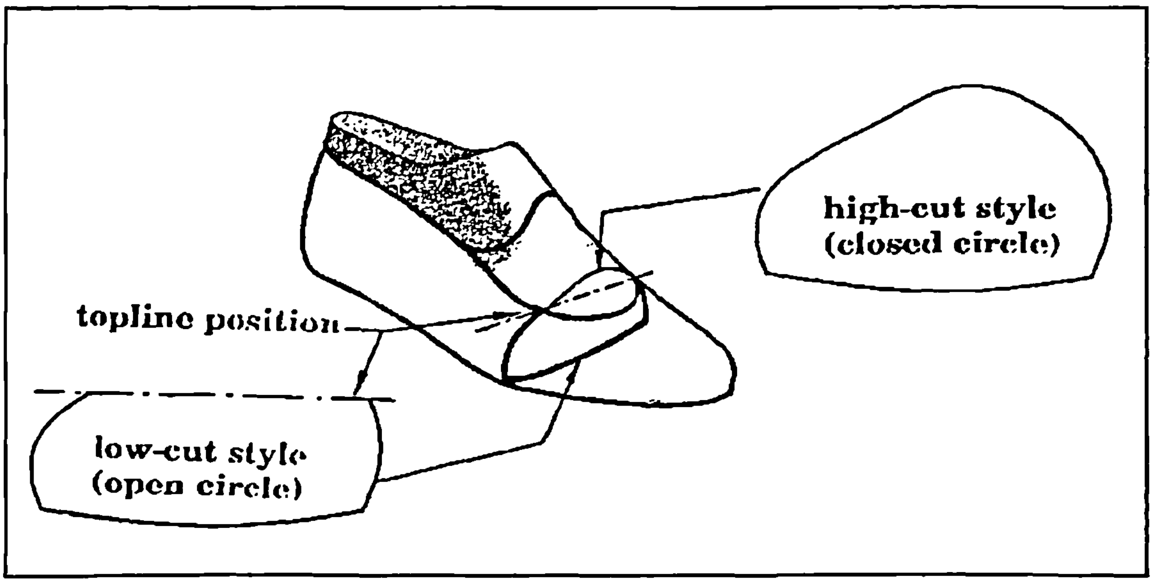


Figure 7.4: THE CROSS-SECTIONAL DIFFERENCE BETWEEN HIGH/LOW CUT STYLES OF SHOE AT THE JOINT REGION.
A: HIGH CUT -- CLOSED CIRCLE SHAPE (CHAPTER 5).
B: LOW CUT -- OPEN CIRCLE SHAPE (SATRA).

In SATRA's fitting trials, a style of women's low-heeled court shoe with low-cut topline and its last were selected to take the cross-section at the joint girth region. There is an open area at the topline position of the cross-section (**Browne, 1993**: figure 1), which enables it to fit a wider range of feet at the joint girth but the reliability is correspondingly lower because the distributed pressure (tension) comes from two different sources, ie. the shoe upper material and the topline reinforcement material. When assessing fit, this pressure might cause some complicated and uncertain fitting results. In the case of the trial in chapter 5, a higher cut toplined style of shoes was selected, and the cross-section in the joint region is a closed shape. This will enable the tolerable fitting allowance to be achieved more accurately.

CHAPTER 8
SUMMARY AND STRATEGY FOR FUTURE WORK

8.1 Summary of the main finding of the research

This thesis has studied the factors of last design and manufacturing and investigated the differences between the shoe last shape and the foot shape, using fit assessment and foot measuring techniques which are refined from methods taken from both the volume and orthopaedic footwear trade.

In chapter 1, the background of this research was introduced by looking at the following areas: the relationship of shoe last and foot shape, development of the shoe industry both in UK and Taiwan, and the difference between volume and orthopaedic shoe making. Chapter 2 contained the general literature search undertaken together with details of visits, interviews and training.

The relationship between the shoe last shape and the foot shape is investigated in chapter 3. In this trial, the accurately measured cross-sectional areas, girth, depth and width are analysed in detail. For the first time the **Theorem of Parallel Cross-sections** is applied to calculate the volume and surface area of the foot and the last. This in turn provides a series of suitable last allowance data leading to further development of shoe last design and manufacture, with a view to upgrading the quality of footwear products.

In chapter 4, the two main shoe-related factors in fit assessment are last shape and construction. A shell shoe fitting method was developed and described in detail. This was seen to be useful in decoupling these two fit assessing factors, as it allows for the assessment of fit **before** the shoe is made. This has potential benefits for bespoke footwear in reducing the number of fitting visits, rework and cost.

Chapter 5 contains a method for last and fit assessment developed to identify the limits of tolerable girth (width) fitting. The term "**tolerance**" as applied to shoe fitting is understood to mean the "**allowances**" which should be added onto the foot measurement to ensure an acceptable shoe fit and enable the feet to perform naturally when active. This method has also been proved useful in helping to improve the design of the model lasts.

Of greater importance is the length tolerance. In chapter 6, the development and design of an in-shoe measuring device is described for measuring the extension of foot length. It is the first time that measurement of foot extension from inside the shoe during standing and walking is reported, paying particular attention to the phases between **heel-lift** and **push-off**. This is a significant area in the design of toe room for the shoe last. The weight-bearing extension and the toe extension are two of the key factors which affect the effective foot extension. By comparing the results, it can be demonstrated that there are more differences than similarities between these two extensions. Most of the phenomenons and results from those trials undertaken, which are inter-related between chapters were analysed and discussed in chapter 7.

8.2 Suggestions for further research

(1) Although some larger UK footwear companies carry out their own confidential foot surveys (viz. C&J Clarks Ltd., Start-Rite Ltd.), it is over 30 years since the size of UK feet was last surveyed, by SATRA footwear technology centre (**Browne, 1989**). The same problem has occurred amongst the Chinese people, the world's largest population (including China, Taiwan, Hong Kong and the overseas Chinese). It is over 25 years since Chinese feet were last surveyed by the **Footwear and Leather Institute (1967)**. An up to date national foot measurement surveys is necessary both in the UK and among the Chinese population.

(2) The geometric approach presented in chapter 3 is very useful for computing the structured data with respect to real and/or complex uncertainties. This cross-sectional method to perform volumetric data and surface areas of the foot and last is particularly successful. The geometric approach used here can be extended to investigate into the other two dimensions (ie. *x-axis* & *y-axis*).

(3) Because the whole study was similar to those used in orthopaedics, the results demonstrated that the shell shoe method can be used in the orthopaedic field. Further tests are needed into the differences between normal and abnormal subjects. It will be important for the orthopaedic shoe/last.

(4) Like fit, the foot comfort factor is a highly subjective judgement and complicated matter depending on the customer's feeling. As discussed in chapter 2, it is not true that comfort automatically follows from a correctly fitted footwear. There are many unknown and uncertain sub-factors within both fit and comfort, which can affect the overall feeling of wearers. This is also an important area needing to be investigated.

(5) Recently, although extra-depth shoes, extra-width shoes and other ready made shoes (eg. DRU-shoes) are becoming popular with foot doctors and orthopaedic shoe-fitters, this only improves the provision and selection of orthopaedic

footwear. There still remains major problems in foot accommodation and shoe fitting which need to be solved.

(6) In order to obtain a more reliable set of results, further work needs to be carried out based on this research and trials would need to involve larger subject groups.

APPENDIX I-I

VISITED & INTERVIEWED COMPANIES

APEX Foot Health Centre,
Mr. Jerome S. Klein
170 Wesley Street,
South Hackensack, New Jersey 07606
USA
TEL: 1-201-4872739 1-800-5262739
FAX: 1-201-4870671

Avalon Components Ltd.,
Mr. Michael Francis
Castle Cary,
Somerset

Blisters (UK) PLC.,
Mr. Steve Curtis
14/16 Midsomer Enterprise Park,
Midsomer Norton,
Bath BA3 2BB
TEL: 44-761-418277
FAX: 44-761-418900

British Leather Confederation,
Dr. Ken Alexander
Leather Trade House,
Kings Park Road,
Moulton Park,
Northampton NN3 1JB
TEL: 44-604-494131
FAX: 44-604-648220
TELEX: 317124 CORIUM G

British United Shoe Machinery (BUSM) Ltd.,
Mr. Tony Garley
P.O.Box 88,
Ross Walk,
Belgrave,
Leicester LE4 5BX
TEL: 44-533-610111
FAX: 44-533-610136

CAMP Ltd.,
Mr. Michael Cheese (General manager); Ms. Sue Mason
30-32 Sovereign Road,
Kings Norton Business Centre,
Birmingham B30 3HN

C&J Clarks International Ltd.,
Fitting Department,
40 High Street,
Street,
Somerset BA16 0YA
TEL: 44-458-43131
FAX: 44-458-47547

De Montfort University,
Mrs. Jenny Whitwam; Mr. Steve Weston; Mr. Keith Walker
P.O.Box 143,
De Montfort University,
School of Design & Manufacturing,
MA Fashion (Footwear) & Textile Studies,
Leicester LE1 9BH
TEL: 44-533-551551 44-533-577542
FAX: 44-533-550307

H.W. Poole & Sons Ltd.,
Mr. Peter Poole
Crispin House,
New York Road,
Leeds
TEL: 44-532-433045

London Foot Hospital,
Mrs. Wood
33 Fitzroy Square,
London W1P 6AY
TEL: 44-71-6360602

Mobbs Miller Ltd.,
Mr. Alan Weston
Carrington Street,
Kettering,
Northants NN16 0DP
TEL: 44-536-512207
FAX: 44-536-410473

PW Minor & Sons (extra depth shoes) INC.,
Mr. Henry H. Minor III
3 Treadeasy Avenue,
P.O.Box 678,
Batavia, NY 14021,
USA
TEL: 1-716-3431500
FAX: 1-716-3431514

RCA (Centrum voor Orthopedietechniek Amsterdam),
Mr. Anton Schouten
Overtoom 283
1054 HW Amsterdam
The Netherlands
TEL: 31-20-6071888
FAX: 31-20-6071896

SATRA Footwear Technology Centre,
SATRA House,
Rockingham Road,
Kettering,
Northants NN16 9JH
TEL: 44-536-410000
FAX: 44-536-410626

Society of Shoe Fitters,
Ms. Laura West
The Anchorage,
28 Admirals Walk,
Hingham,
Norfolk NR9 4JL
TEL: 44-953-851171

TNO (Centre for Leather and Shoe Research),
Mr. Marc van der Zande
Mr. van Coothstraat 55,
P.O.Box 135,
5140 AC Waalwijk,
The Netherlands
TEL: 31-4160-84266
FAX: 31-4160-41735

VA Medical Centre,
Dr. Vern L. Houston
252, 7th Ave.,
New York City, NY 10010
USA

APPENDIX II-I

OSSIFICATION TIMETABLE

BONE	APPEARANCE OF CENTRE OF OSSIFICATION		FUSION
	PRIMARY	SECONDAR Y	
Tibia-Diaphysis	7th week	-	-
Tibia-Upper Epiphysis	-	at birth	20th year
Tibia-Lower Epiphysis	-	2nd year	18th year
Fibula-Diaphysis	8th week	-	-
Fibula-Upper Epiphysis	-	4th year	25th year
Fibula-Lower Epiphysis	-	2nd year	20th year
Calcaneum Body	6th month	-	-
Calcaneum Epiphysis	-	6-10th year	13rd-15th year
Talus	7th month	-	-
Cuboid	at birth	-	-
Lat. Cuneiform	1st year	-	-
Med. Cuneiform	3rd year	-	-
Int. Cuneiform	4th year	-	-
Navicular	4th year	-	-
1st Met. Shaft	8-9th week	-	-
1st Met. Base	-	3rd year	17th-20th year
Other Met. Shafts	8-9th week	-	-
Other Met. Heads	-	3-4th year	16th-18th year
Prox. Phals. Shafts	12-16th week	-	-
Prox. Phals. Bases	-	3-6th year	17th-18th year
Int. Phals. Shafts	4-9th month	-	-
Int. Phals. Bases	-	3-6th year	17th-18th year
Dist. Phals. Shafts	8th week	-	-
Dist. Phals. Bases	-	6th year	17th-18th year

APPENDIX II-II
LAST DEFINITIONS

BACKPART

That position of the last roughly lying to the rear of the front region.

BACKPART WIDTH

The distance between the inner and outer swells of the seat region measured at a defined distance from the extreme end of the last. The measurement is normally taken on a line which is parallel to the seat plane.

BOTTOM WIDTH

The width across the last between the inner and outer feather edges at the joint position. There are many methods of defining this measurement all of which will give slightly different results.

CONE

That part of the last between the vamp region and the "V" cut adjacent to the instep region.

FOREPART

That portion of the last lying forward of the joint region.

FEATHER LINE

The edge of the bottom surface of the last.

GRADE

Change in dimensions between sizes can apply to either length or width.

GRADE LINE

Rate at which the joint girth changes in relation to the length.

GIRTH

The distance round the last at any of the specified points. These are usually joint, waist and instep girth.

GROUND PLANE

The plane upon which the last rests when on its proper attitude. It is used as a reference from which to measure toe spring and heel pitch.

HEEL CURVE

The curve at the extreme back of the last.

HEEL SEAT

The bottom surface of the heel end of the last.

HEEL SEAT WIDTH

The distance between the feather line across the seat measured at a defined distance from the extreme heel end of the last.

HINGE

The mechanism used to link the forepart and backpart of the last and to provide a tension to keep them together to provide stability during use. The hinge provides means by which the last shortens to facilitate its release from the shoe.

HEEL PITCH

The vertical height between the underside of the extreme end of the last and the ground plane.

INSTEP GIRTH

The dimension around the last passing through the instep point. This measurement can have a number of values depending upon how the tape is positioned round the last. Normally it is allowed to be flat and such that it passes over its starting position.

INSTEP POINT

A position which can have a number of definitions but roughly associated with the actual position that the instep will occupy in the finished footwear.

JOINT

The inner joint position is that region where the inner joint of the foot[1] would be expected to lie. It is usually associated with a prominence to accommodate the joint. The outer joint is a region that similarly accommodates the outer joint[2].

JOINT REGION

An area of the last in the proximity of a line joining the inside and outside joint.

---

[1] Where the big toe bones articulate with the 1st metatarsal.

[2] Where the little toe bones articulate with the 5th metatarsal.

JOINT GIRTH

The dimensions around the last in the region of the inner and outer joint. As with the instep girth there are many methods of taking this measurement all of which give slightly different results.

LONG HEEL GIRTH

That girth around the last measured with the tape passing through the instep point and the extreme end of the bottom surface of the last.

SEAT ANGLE

The angle between the seat plane and the ground plane.

SWELLS

Bulge of the last in the region above the seat plane.

SEAT PLANE

The plane which is coincidental with the feather line in the seat region. There are a number of different methods of defining this plane.

THIMBLE

A metal sleeve inserted into the top plane of the last to provide a means of locating it for various shoemaking process.

TOE SPRING

The vertical distance between the underside of the last at the extreme heel end and the ground plane.

TOP PLANE

The top surface of the last in the backpart.

VAMP REGION

The front region of the last where the vamp of the shoe will lie.

WAIST GIRTH

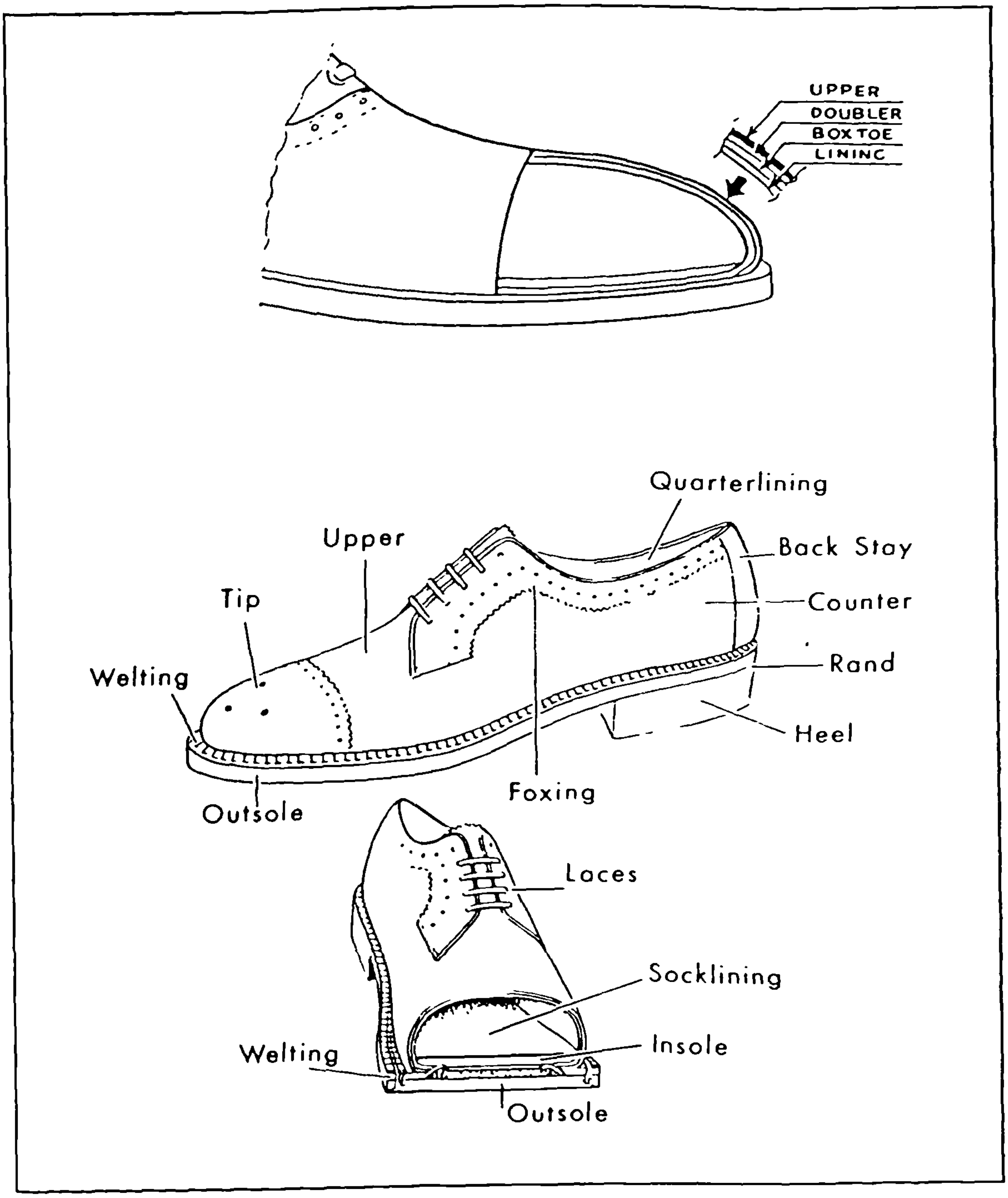
The smallest girth around the last between the instep and the joint girth.

(Larcombe, 1990: 3)

APPENDIX II-III

ANATOMY OF A SHOE (1/3)

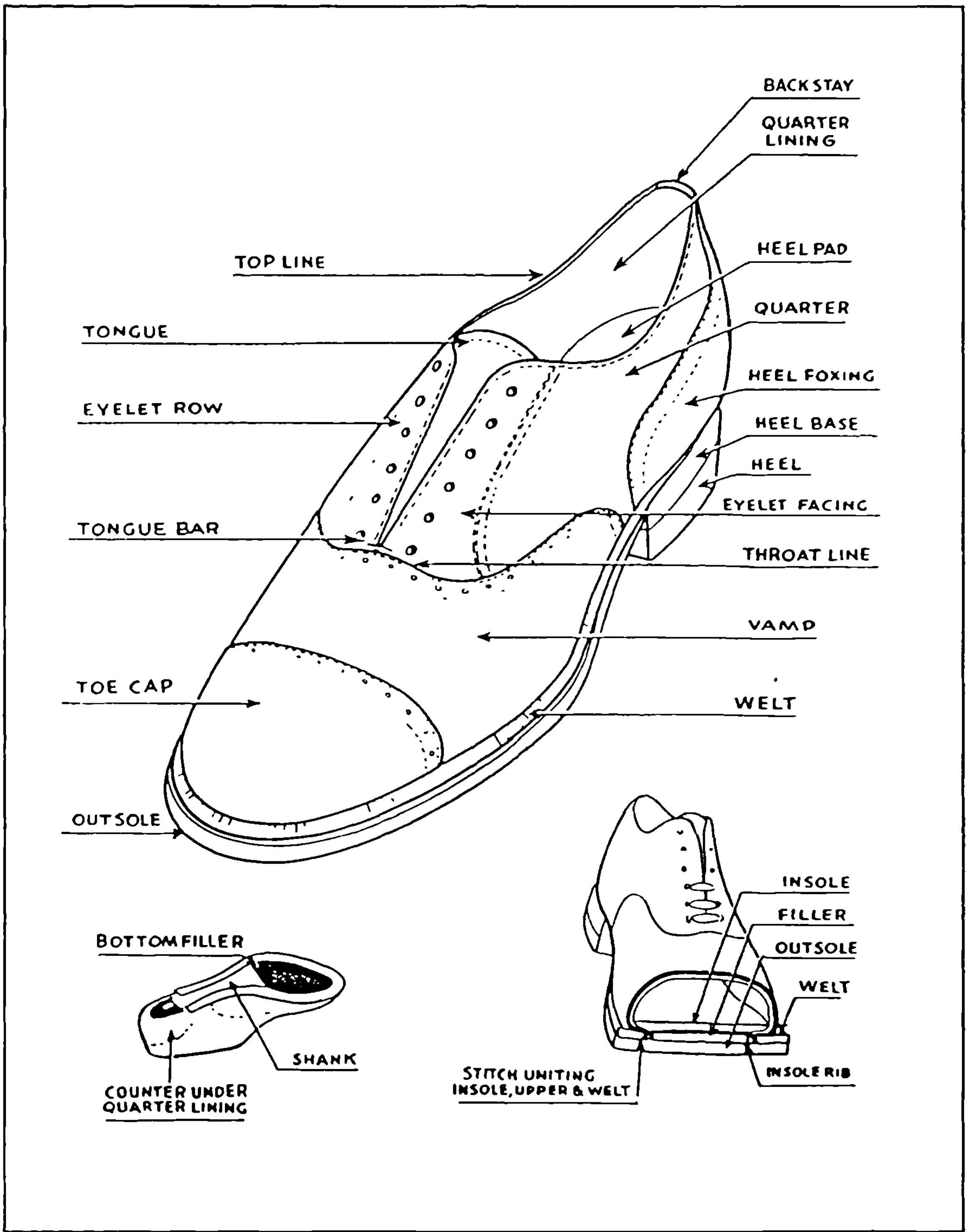
(SOURCE: ROSSI & TENNANT, 1984)



ANATOMY OF A SHOE.

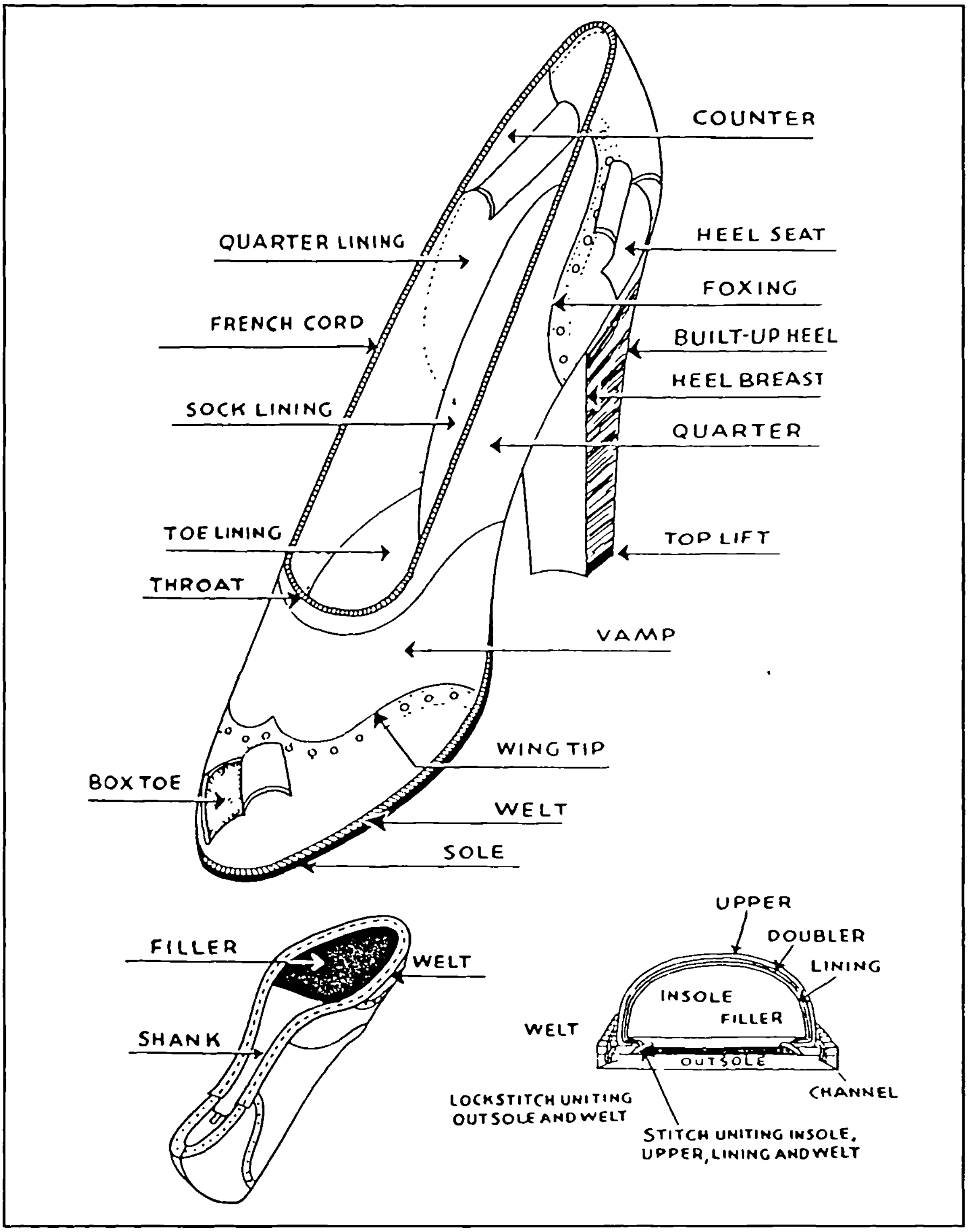
ANATOMY OF A SHOE (2/3)

(SOURCE: ROSSI & TENNANT, 1984)



PARTS & CONSTRUCTION OF A MEN'S GOODYEAR WELT PROCESS.

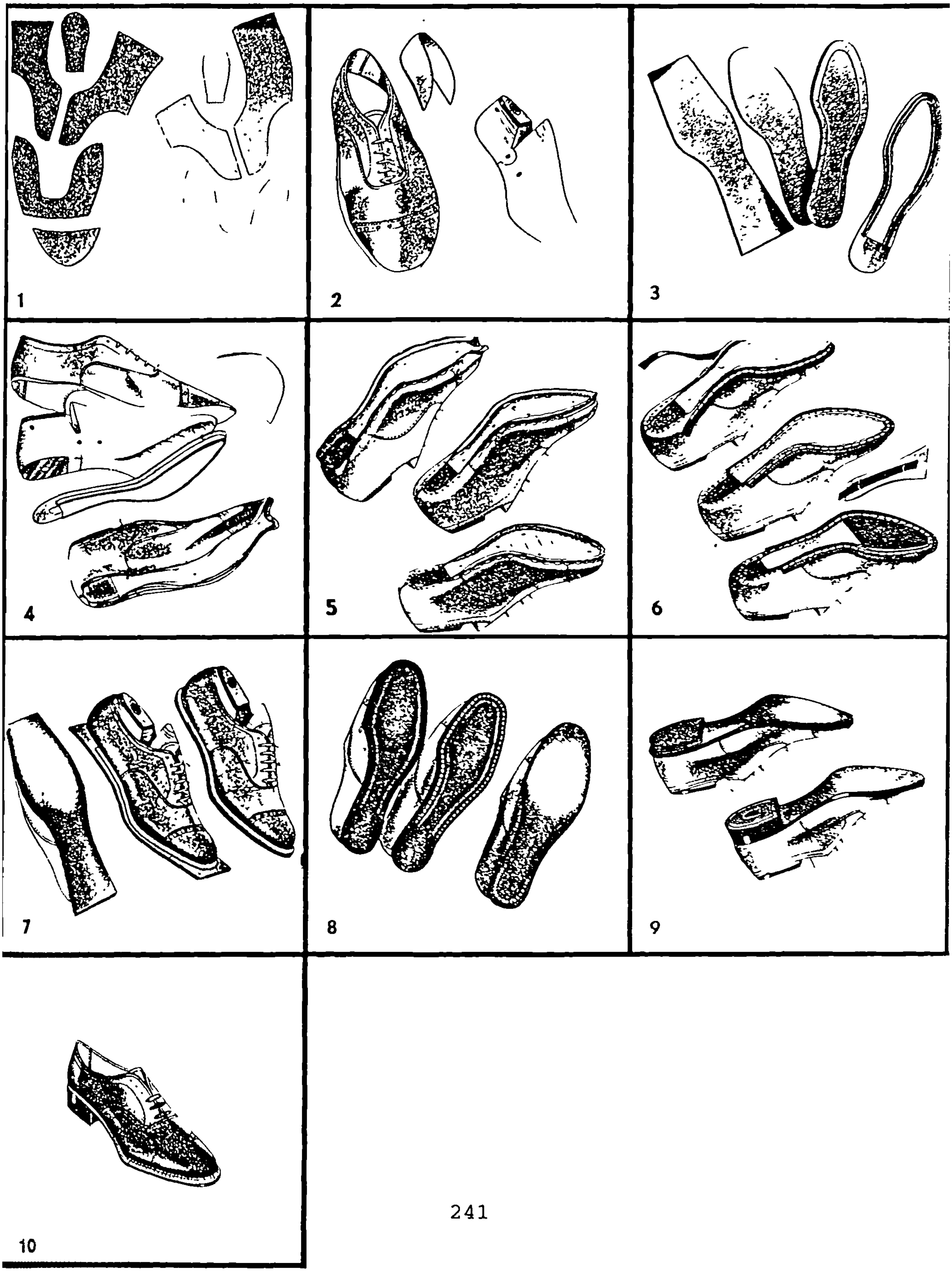
ANATOMY OF A SHOE (3/3)
(SOURCE: ROSSI & TENNANT, 1984)



PARTS & CONSTRUCTION OF A WOMEN'S GOODYEAR WELT PROCESS.

APPENDIX II-IV

HOW A GOODYEAR WELT MEN'S SHOE IS ASSEMBLED



APPENDIX II-V

FOOT MEASUREMENT SYSTEM (1/3)

(BRITISH STANDARD INSTITUTION: BSL, 1980)

(unit: mm)

SUBJECT NAME			RIGHT	LEFT
1	Initial Information (II) *			
2	Outline Diagram (OD) **			
3	Foot Length (FL)			
4	Joint Girth (JG)			
5	Waist Girth (WG)			
6	Instep Girth (IG)			
7	Long Heel Girth (LHG)			
8	Short Heel Girth (SHG)			
9	Malleoli Girth/Height (MG/H)			
10	Ankle Girth/Height (AG/H)			
11	Top Girth/Height (TG/H)			
12	Calf Girth/Height (CG/H)			
13	Thigh Girth/Height (ThG/H)			
14	Dorsum Height (DH)			
15	Medial Malleolus Height (MMH)			
16	Lateral Malleolus Height (LMH)			
*				

DATE: / /

** OUTLINE DIAGRAM
RIGHT FOOT

** OUTLINE DIAGRAM
LEFT FOOT

FOOT MEASUREMENT SYSTEM (2/3)
(C&J CLARKS INTERNATIONAL LIMITED)

(unit: mm)

		RIGHT	LEFT
SUBJECT NAME			
1	Foot Length (FL)		
2	Joint Girth (JG)		
3	Instep Girth (IG)		
4	Long Heel Girth (LHG)		
5	Short Heel Girth (SHG)		
6	Ankle Girth (AG)		
7	Big Toe Height (BTH)		
8	5th Metatarsal-head Height (5MH)		
9	1st Metatarsal-head Height (1MH)		
10	Instep Height (IH)		
11	Short Heel Height (SHH)		
12	Heel to Short Heel Length (HSHL)		
13	Joint Width (JW)		
14	Seat Width (SW)		
15	Heel to Ankle Length (HAL)		
16	Lateral Heel to Ball Length(LHBL)		
17	Medial Heel to Ball Length (MHBL)		
18	Heel to Smallest Toe Length(HSTL)		
19	Outline Diagram (OD) *		

DATE: / /

* OUTLINE DIAGRAM
RIGHT FOOT

* OUTLINE DIAGRAM
LEFT FOOT

FOOT MEASUREMENT SYSTEM (3/3)
(SATRA FOOTWEAR TECHNOLOGY CENTRE)

(unit: mm)

SUBJECTS NUMBER		
ITEMS / FOOT	RIGHT	(LEFT)
Foot (Stick) Length		
Heel to Medial Joint		
Heel to Lateral Joint		
Heel to Medial Ball		
Heel to Lateral Ball		
Heel to Instep (Long Heel Point)		
Heel to Throat (Short Heel Point)		
Heel to Medial Malleolus		
Heel to Lateral Malleolus		
Heel to Smallest Toe		
Heel to 5th Metatarsal Base		
Heel to Seat		
1st Toe Length		
5th Toe Length		
Joint Girth		
Waist Girth		
Instep Girth		
Long Heel Girth		
Short Heel Girth		
Malleoli Girth		
Minimum Ankle Girth		
Calf Girth		
1st Toe Height		
5th Toe Height		
Highest Toe Height		
1st Metatarsal Height		
5th Metatarsal Height		
Instep Height		
Short Heel Height		
Medial Malleolus Height		
Lateral Malleolus Height		
Under Ankle Height		
Under Knee Height		
Joint Width		
Seat Width		
Instep to Medial Tangent Distance		
1st Toe Angle		
5th Toe Angle		
Joint Angle		

DATE: / /

APPENDIX II-VI

SHOE SIZE CONVERSION (1/3)

(SOURCE: SATRA FOOTWEAR TECHNOLOGY CENTRE)

SHOE SIZE CONVERSION:

FROM ENGLISH TO CONTINENTAL

ENGLISH SIZE	CONTINENTAL NEAREST SIZE	ENGLISH SIZE	CONTINENTAL NEAREST SIZE
3	19	2	34 $^1/_2$
3 $^1/_2$	19 $^1/_2$	2 $^1/_2$	35
4	20 $^1/_2$	3	35 $^1/_2$
4 $^1/_2$	21	3 $^1/_2$	36
5	21 $^1/_2$	4	37
5 $^1/_2$	22	4 $^1/_2$	37 $^1/_2$
6	23	5	38
6 $^1/_2$	23 $^1/_2$	5 $^1/_2$	38 $^1/_2$
7	24	6	39 $^1/_2$
7 $^1/_2$	25	6 $^1/_2$	40
8	25 $^1/_2$	7	40 $^1/_2$
8 $^1/_2$	26	7 $^1/_2$	41 $^1/_2$
9	26 $^1/_2$	8	42
9 $^1/_2$	27 $^1/_2$	8 $^1/_2$	42 $^1/_2$
10	28	9	43
10 $^1/_2$	28 $^1/_2$	9 $^1/_2$	44
11	29	10	44 $^1/_2$
11 $^1/_2$	30	10 $^1/_2$	45
12	30 $^1/_2$	11	45 $^1/_2$
12 $^1/_2$	31	11 $^1/_2$	46 $^1/_2$
13	32	12	47
13 $^1/_2$	32 $^1/_2$	12 $^1/_2$	47 $^1/_2$
1	33	13	48 $^1/_2$
1 $^1/_2$	33 $^1/_2$		

SHOE SIZE CONVERSION (2/3)

(SOURCE: SATRA FOOTWEAR TECHNOLOGY CENTRE)

SHOE SIZE CONVERSION:

FROM CONTINENTAL TO ENGLISH

CONTINENTAL SIZE	ENGLISH NEAREST SIZE	CONTINENTAL SIZE	ENGLISH NEAREST SIZE
19	3	33 1/2	1 1/2
19 1/2	3 1/2	34	2
20	4	34 1/2	2
20 1/2	4	35	2 1/2
21	4 1/2	35 1/2	3
21 1/2	5	36	3 1/2
22	5 1/2	36 1/2	3 1/2
22 1/2	5 1/2	37	4
23	6	37 1/2	4 1/2
23 1/2	6 1/2	38	5
24	7	38 1/2	5 1/2
24 1/2	7 1/2	39	5 1/2
25	7 1/2	39 1/2	6
25 1/2	8	40	6 1/2
26	8 1/2	40 1/2	7
26 1/2	9	41	7 1/2
27	9 1/2	41 1/2	7 1/2
27 1/2	9 1/2	42	8
28	10	42 1/2	8 1/2
28 1/2	10 1/2	43	9
29	11	43 1/2	9 1/2
29 1/2	11	44	9 1/2
30	11 1/2	44 1/2	10
30 1/2	12	45	10 1/2
31	12 1/2	45 1/2	11
31 1/2	13	46	11
32	13	46 1/2	11 1/2
32 1/2	13 1/2	47	12
33	1	47 1/2	12 1/2
		48	13
		48 1/2	13

SHOE SIZE CONVERSION (3/3)

(SOURCE: SATRA FOOTWEAR TECHNOLOGY CENTRE)

SHOE SIZE CONVERSION:

FROM ENGLISH TO CHINESE, JAPANESE[3]

ENGLISH SIZE (ADULT)	CHINESE & JAPANESE NEAREST SIZE
3	22
3 1/2	22 1/2
4	23
4 1/2	23 1/2
5	23 1/2
5 1/2	24
6	24 1/2
6 1/2	25
7	25 1/2
7 1/2	26
8	26
8 1/2	26 1/2
9	27
9 1/2	27 1/2
10	28
10 1/2	28 1/2
11	29
11 1/2	29
12	29 1/2

[3] The Chinese and Japanese systems are similar to Mondopoint. A centimetre scale indicating the length of foot that will best fit the shoe is used.

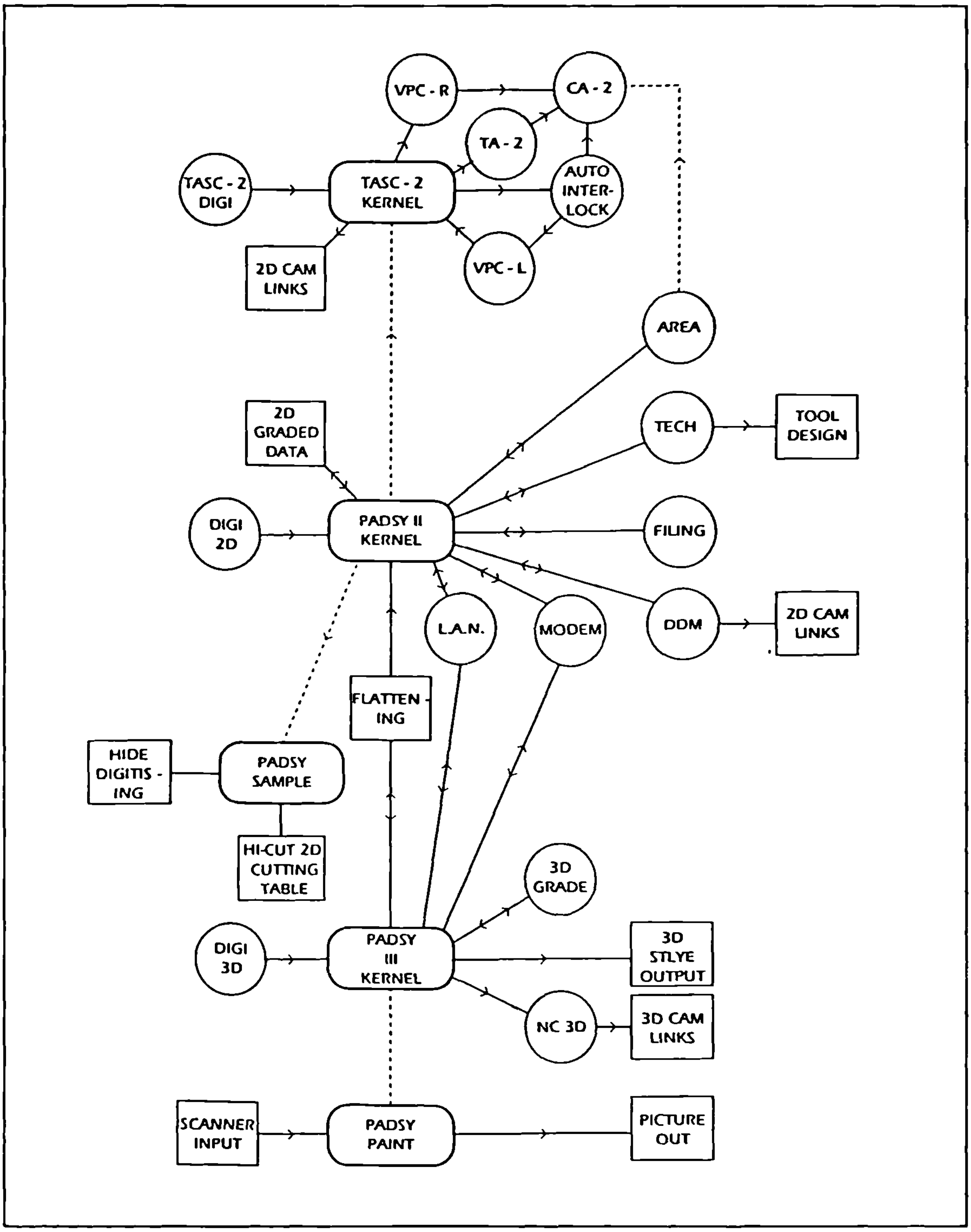
For the length grading, **1 cm** between full sizes (1/2 cm between half sizes), and normally **6 mm** interval of the girth grading.

As a general rule the shoe/last is normally **10 mm** longer than the foot. Fittings are usually presented by letters.

The men's will take the equivalent of a UK **size 6** on average, and have joint girths **1 fitting** wider than that of UK average for this size. The women's is equivalent to a UK size 3 1/2, and joint girths are 1 1/2 fitting wider than that of UK average of this size.

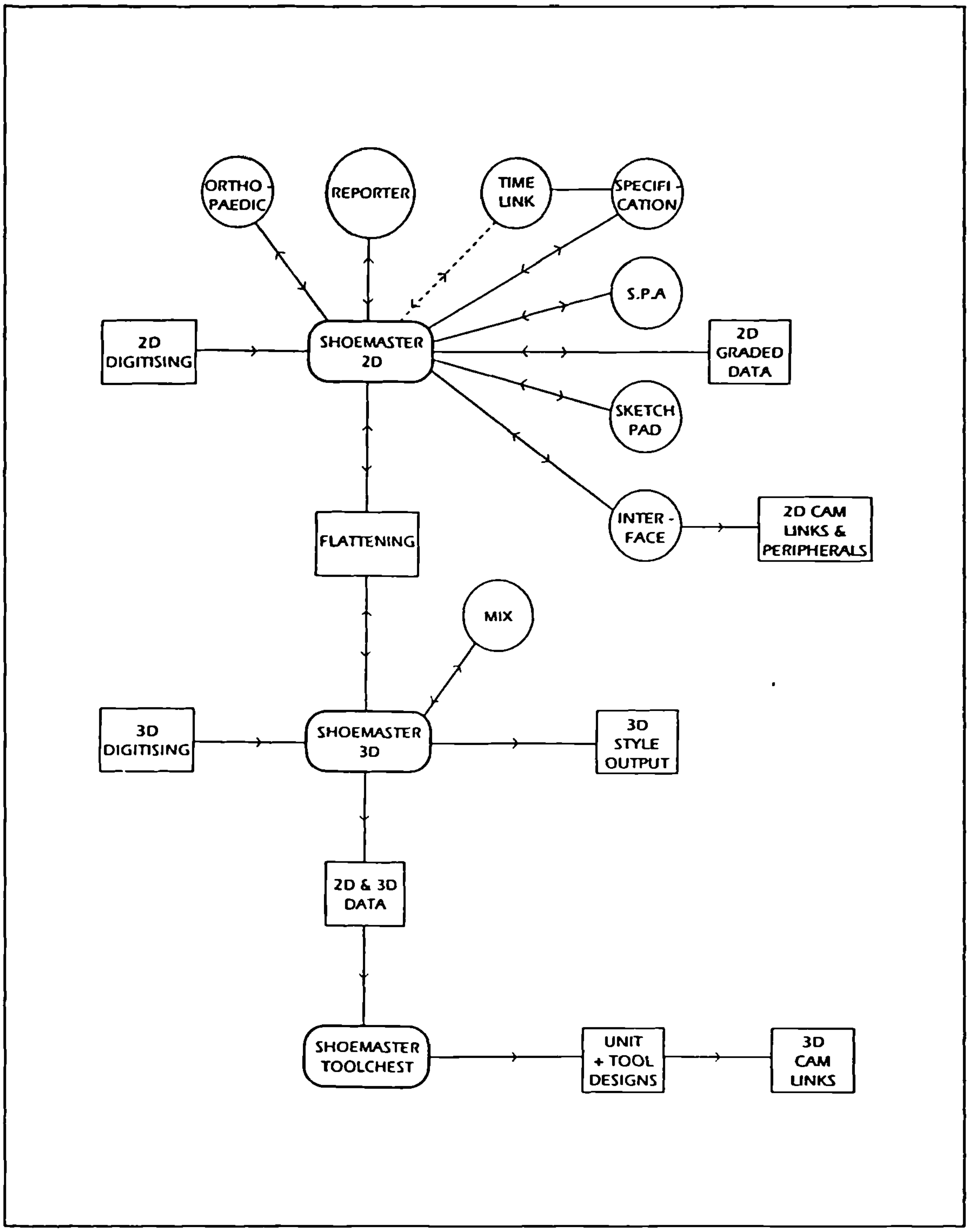
APPENDIX II-VII

COMMERCIAL SHOE CAD/CAM SYSTEM LAYOUT (1/6)



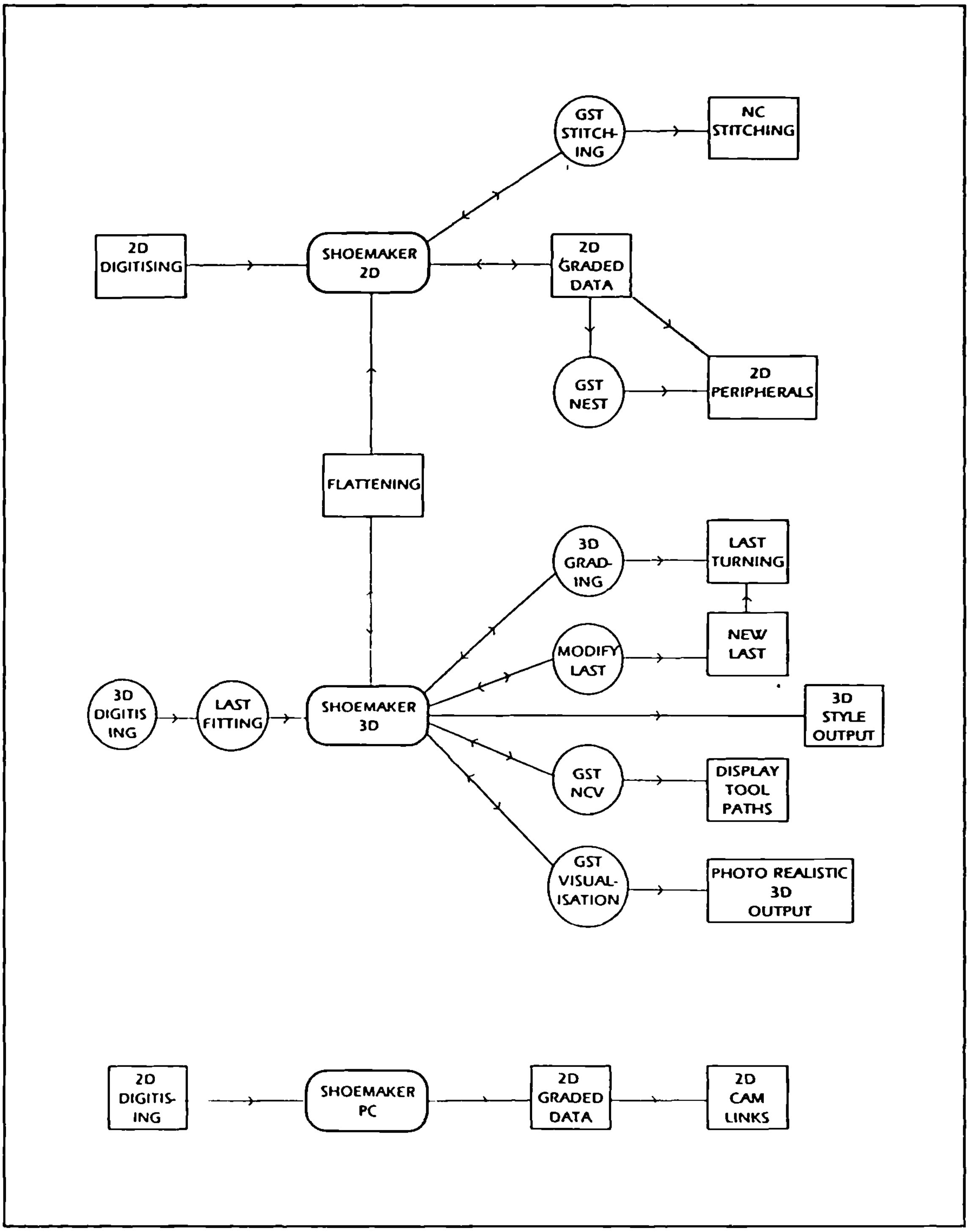
ATOM+VICAM SYSTEMS LAYOUT.

COMMERCIAL SHOE CAD/CAM SYSTEM LAYOUT (2/6)



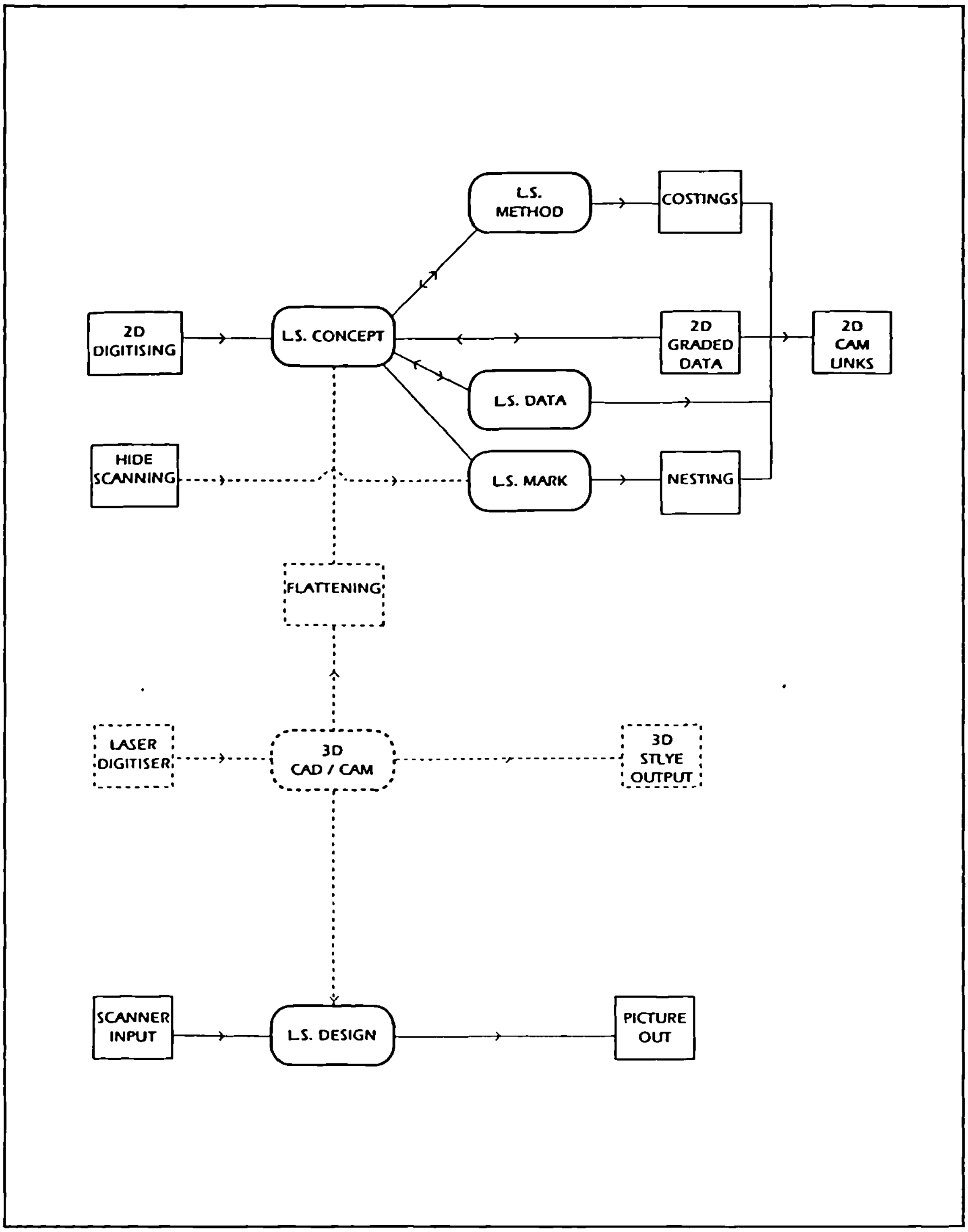
CLARKS' SHOEMASTER SYSTEMS LAYOUT.

COMMERCIAL SHOE CAD/CAM SYSTEM LAYOUT (3/6)



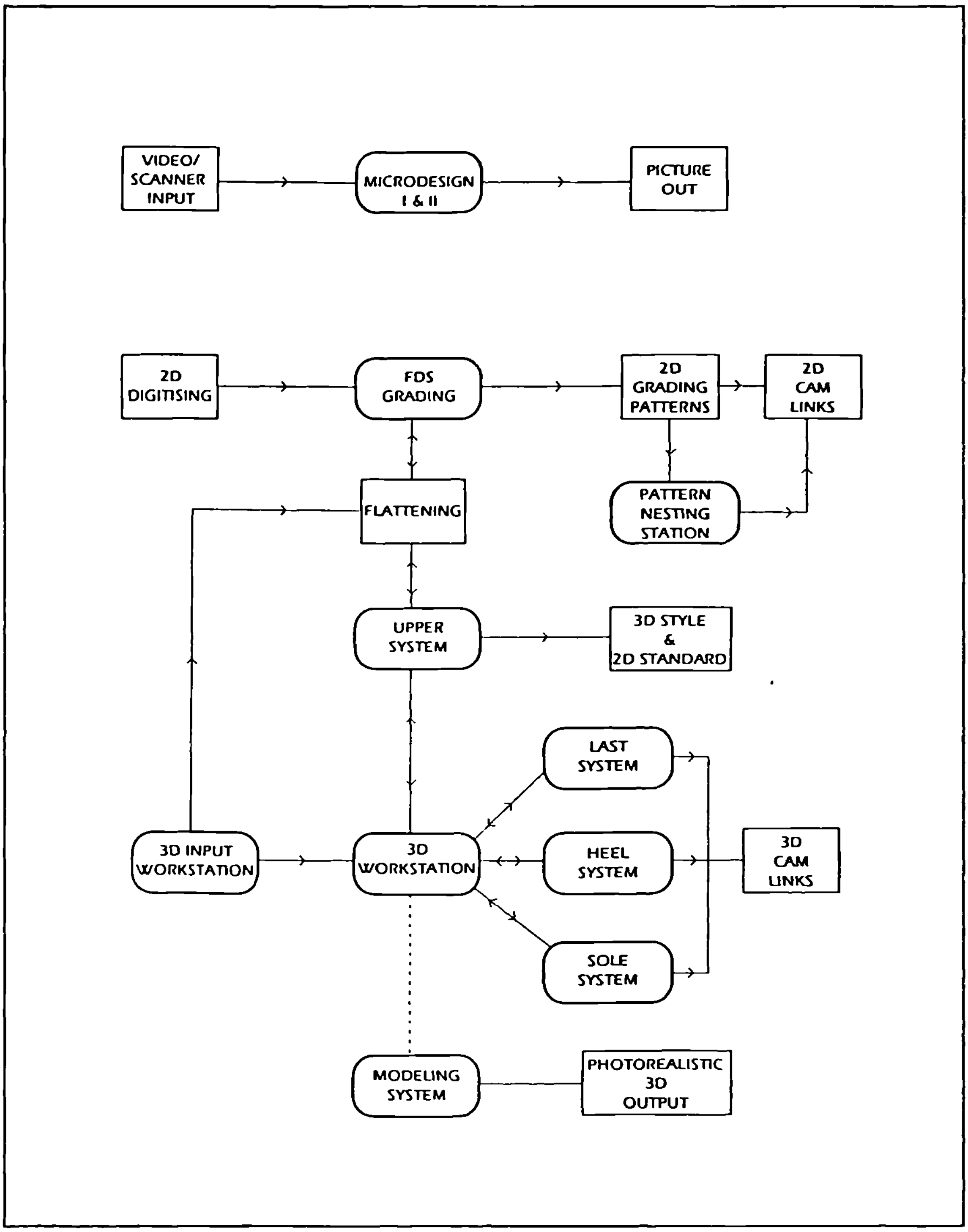
GERBER'S SYSTEMS LAYOUT.

COMMERCIAL SHOE CAD/CAM SYSTEM LAYOUT (4/6)



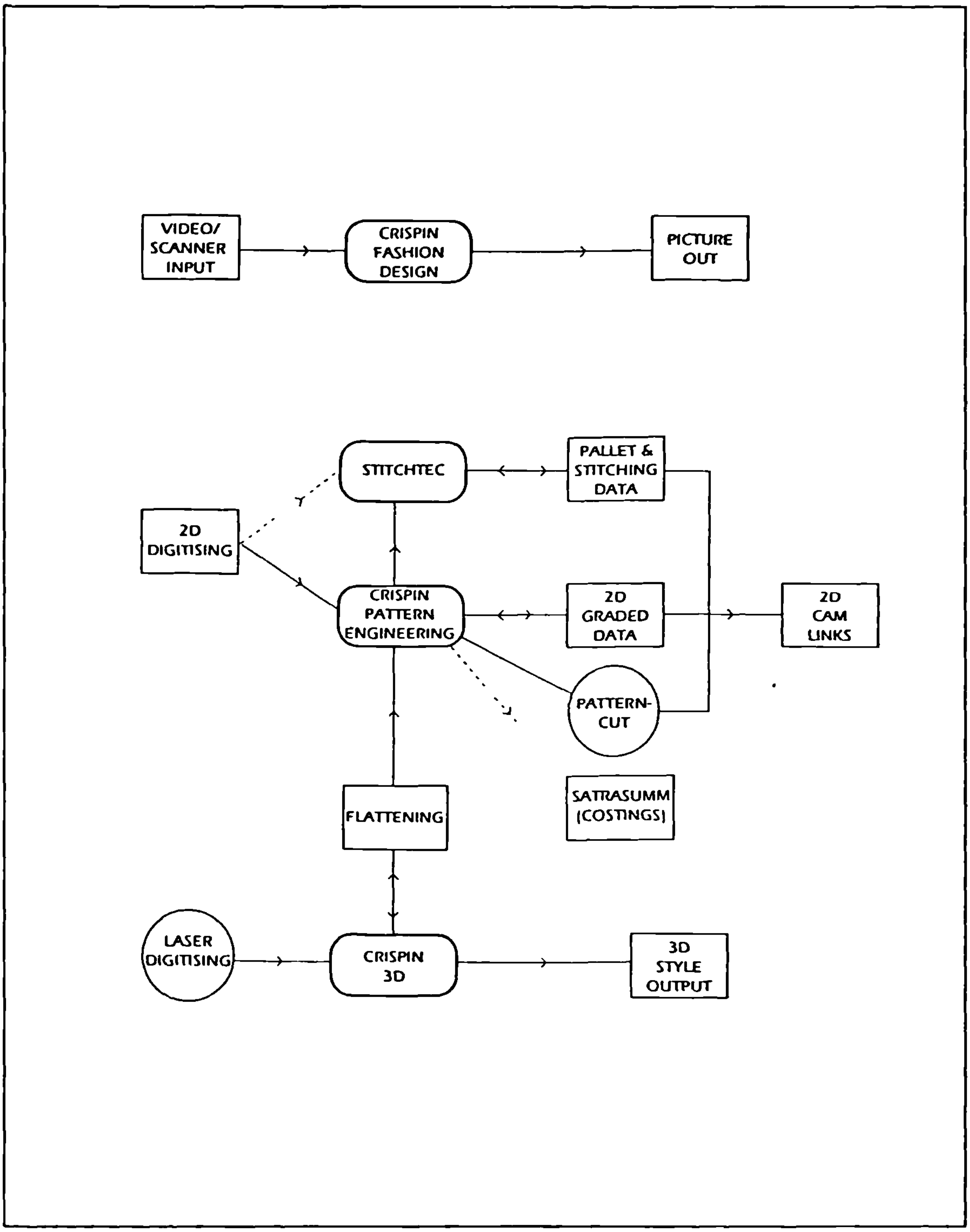
LECTRA SYSTEMS LAYOUT.

COMMERCIAL SHOE CAD/CAM SYSTEM LAYOUT (5/6)



MICRODYNAMICS SYSTEMS LAYOUT.

COMMERCIAL SHOE CAD/CAM SYSTEM LAYOUT (6/6)



USM SYSTEMS LAYOUT.

APPENDIX III-I

DIGITISED LAST DATA (C&J CLARKS SHOEMASTER)

LAST-H6028S

```
$( release_3.30 $)

     Disable thickness
new model 5d
units mm
position
      -0.001          0.100 100.000
      -0.001          0.100        -0.003
     244.291         -0.110        -0.291
pitch       0.5
new sole u 11 by v 4

p     2.434     9.433     0.255
p     0.766     4.207    -0.045
p    -0.001     0.100    -0.003
p    -0.165    -5.008    -0.147
p     0.679    -9.897     0.075

p     6.497    15.883     0.654
p     5.626     7.735    -0.582
p     5.178    -0.486    -1.026
p     4.127    -7.100    -1.102
p     2.812   -14.687    -0.140

p    17.162    22.995     1.256
p    15.711    10.121    -0.625
p    14.081    -0.511    -1.066
p    13.656   -11.530    -1.428
p    12.692   -24.103    -0.028

p    32.149    24.920     1.094
p    31.022     9.756    -0.527
p    29.592    -1.783    -1.247
p    28.797   -15.296    -1.225
p    27.963   -30.055     0.637

p    59.803    21.675     1.744
p    58.358     7.396    -0.295
p    57.224    -4.044    -1.126
p    56.839   -18.652    -1.082
p    55.616   -33.806     1.102

p    85.914    18.977     1.019
p    85.660     4.495    -1.447
p    84.630    -7.041    -2.177
p    84.039   -21.354    -2.237
p    83.400   -35.915    -0.487

p   123.490    21.571    -3.376
p   122.340     5.977    -5.985
p   121.522    -8.065    -6.947
p   121.049   -24.376    -6.950
p   120.625   -40.735    -5.152

p   155.680    30.798    -5.220
p   155.034    10.974    -8.918
p   154.337    -6.677   -10.176
p   154.494   -25.574    -9.820
p   153.830   -46.006    -6.994

p   187.003    33.300    -4.139
p   187.151    14.082    -7.876
p   187.067    -4.458    -8.925
p   187.017   -22.254    -8.495
p   186.357   -42.883    -5.563

p  209.989    29.346    -2.441
p  210.524    13.850    -5.598
p  211.533    -2.065    -6.154
p  211.255   -17.473    -6.089
p  211.253   -34.510    -3.682

p  234.946    18.018    -0.277
p  235.375     8.669    -1.912
p  235.838    -0.641    -2.249
p  236.117   -10.138    -2.075
p  236.511   -18.811    -1.127

p  240.295    12.465    -0.156
p  243.449     6.092    -0.052
p  244.291    -0.110    -0.291
p  243.740    -6.115    -0.198
p  240.592   -13.954    -0.481
check
spline
units mm
position
    1.138    -0.064    64.038
   -0.001     0.100    -0.003
  244.291    -0.110    -0.291
pitch       0.5
new upper u 22 by v 9

p    -0.001     0.100,   -0.003
p    -2.902    -0.033     6.720
p    -4.867     0.143    13.651
p    -6.164     0.450    21.174
p    -6.262     0.222    27.976
p    -5.751     0.168    34.567
p    -4.373     0.148    41.807
p    -2.803     0.072    49.203
p    -0.973     0.062    56.416
p     1.138    -0.064    64.038

p     2.812   -14.687    -0.140
p     0.536   -15.285     6.686
p    -0.959   -14.723    14.063
p    -1.143   -14.226    21.303
p    -0.875   -13.255    27.388
p    -0.448   -11.610    34.022
p     0.750    -9.878    41.200
p     2.416    -8.581    49.181
p     3.217    -7.467    56.505
p     4.339    -6.835    63.618

p    12.692   -24.103    -0.028
p    11.445   -26.180     6.826
p    10.762   -25.692    14.040
p    11.446   -23.271    21.231
p    12.061   -20.102    27.559
p    13.304   -17.298    33.497
p    13.666   -14.295    40.905
p    14.012   -12.024    48.874
p    13.598   -10.848    56.440
p    13.209   -10.566    63.858

p    27.963   -30.055     0.637
p    27.157   -31.772     7.109
p    26.687   -30.958    13.950
p    26.668   -27.839    20.945
p    27.175   -24.068    27.201
p    27.485   -20.399    33.441
```

p	28.378	-17.148	40.188
p	28.455	-14.848	47.543
p	28.074	-13.234	56.239
p	27.964	-12.969	64.071

p	55.616	-33.806	1.102
p	55.224	-35.632	8.016
p	54.076	-34.604	14.334
p	52.760	-31.099	21.084
p	51.835	-26.676	27.704
p	51.305	-23.368	32.879
p	50.609	-19.829	39.261
p	49.281	-17.256	46.559
p	48.073	-15.485	55.724
p	46.727	-14.976	64.109

p	83.400	-35.915	-0.487
p	82.668	-37.785	6.781
p	81.294	-37.199	13.765
p	80.326	-34.247	19.799
p	78.511	-30.036	26.263
p	76.717	-25.802	32.327
p	74.046	-22.377	38.202
p	71.120	-19.323	45.246
p	68.445	-17.040	55.468
p	65.772	-16.384	64.295

p	120.625	-40.735	-5.152
p	119.496	-43.221	1.526
p	117.596	-42.878	9.071
p	111.144	-38.296	17.927
p	106.133	-33.633	24.053
p	100.902	-28.691	30.485
p	96.078	-24.856	37.175
p	92.316	-21.757	44.881
p	86.682	-18.985	55.984
p	80.144	-17.461	67.572

p	153.830	-46.006	-6.994
p	154.157	-48.271	-0.708
p	151.866	-48.334	6.793
p	144.878	-45.532	15.021
p	136.013	-38.349	21.194
p	128.302	-32.515	26.847
p	118.670	-26.544	34.718
p	109.219	-21.823	45.335
p	98.858	-19.182	58.798
p	89.382	-17.657	71.039

p	186.357	-42.883	-5.563
p	186.574	-44.850	0.630
p	185.305	-45.277	7.863
p	181.079	-43.068	15.194
p	171.942	-38.714	19.889
p	160.588	-33.197	24.438
p	144.675	-26.010	33.261
p	126.909	-21.070	45.775
p	109.461	-18.360	60.686
p	96.386	-17.117	74.835

p	211.253	-34.510	-3.682
p	211.716	-36.248	3.295
p	211.499	-35.985	9.317
p	207.753	-33.473	14.984
p	196.807	-29.874	18.141
p	179.938	-25.301	23.159

p	160.607	-20.757	33.164
p	140.278	-17.778	47.543
p	121.012	-16.349	63.192
p	104.377	-15.754	78.627

p	236.511	-18.811	-1.127
p	236.936	-19.295	5.333
p	235.954	-18.813	12.531
p	230.862	-18.101	15.822
p	214.323	-16.541	17.477
p	192.791	-13.963	22.345
p	170.792	-12.197	32.660
p	149.593	-11.559	49.169
p	129.893	-11.403	65.928
p	111.143	-11.479	81.819

p	244.291	-0.110	-0.291
p	244.456	-0.144	6.094
p	243.116	-0.644	12.817
p	237.609	-0.878	16.736
p	221.946	-1.261	17.623
p	197.861	-1.237	22.418
p	174.051	-2.279	33.886
p	153.574	-3.441	50.632
p	132.865	-4.746	68.059
p	113.239	-4.916	83.500

p	234.946	18.018	-0.277
p	236.031	18.747	5.428
p	234.993	18.563	11.984
p	227.977	17.369	16.374
p	211.264	15.786	18.644
p	189.419	13.132	29.608
p	170.511	10.666	35.741
p	149.413	6.613	51.991
p	129.096	4.089	68.065
p	110.365	1.893	82.434

p	209.989	29.346	-2.441
p	209.232	31.175	4.065
p	207.169	31.044	11.074
p	199.865	29.135	17.414
p	189.873	25.967	21.943
p	174.337	22.836	29.100
p	160.245	19.060	37.598
p	138.783	13.003	51.911
p	119.815	8.828	65.755
p	104.136	6.444	79.266

p	187.003	33.300	-4.139
p	185.185	35.648	2.695
p	179.591	35.923	10.048
p	171.379	34.492	18.275
p	162.412	31.875	24.090
p	151.275	27.094	31.980
p	142.751	23.410	37.356
p	124.288	15.477	50.512
p	109.026	10.981	62.521
p	96.592	9.018	75.116

p	155.680	30.798	-5.220
p	151.757	33.523	1.077
p	145.713	33.735	9.407
p	139.060	32.904	18.249
p	132.532	30.166	25.384
p	124.930	26.210	32.397

```
p  118.784   22.242   38.379
p  108.430   16.533   48.864
p   97.912   12.896   59.858
p   88.660   10.064   71.262

p  123.490   21.571   -3.376
p  121.920   26.345    3.469
p  118.276   28.948   12.958
p  113.864   29.023   20.761
p  109.856   27.585   27.095
p  105.394   24.758   33.027
p  101.256   21.553   38.653
p   94.547   17.193   47.895
p   87.672   13.572   58.172
p   80.393   11.065   68.091

p   85.914   18.977    1.019
p   86.285   24.657    7.580
p   84.656   26.815   15.041
p   82.991   26.996   21.986
p   81.416   25.847   27.658
p   79.366   23.080   33.415
p   76.896   19.774   39.722
p   73.920   15.931   48.280
p   70.128   13.283   56.663
p   66.224   11.742   64.902

p   59.803   21.675    1.744
p   59.420   25.683    7.677
p   58.166   27.309   15.829
p   56.338   26.505   22.410
p   55.835   23.917   29.158
p   54.527   21.109   34.148
p   53.014   17.570   41.393
p   51.590   14.838   48.588
p   49.828   12.670   56.299
p   47.425   11.262   64.521

p   32.149   24.920    1.094
p   32.908   27.481    8.438
p   32.464   27.302   15.124
p   32.230   25.196   22.315
p   32.681   22.276   28.190
p   33.062   18.461   35.716
p   33.487   15.718   42.001
p   33.647   13.409   49.401
p   33.101   11.896   56.609
p   32.726   10.970   64.159

p   17.162   22.995    1.256
p   16.664   24.458    7.943
p   16.719   24.083   14.744
p   16.888   22.090   21.861
p   16.709   19.330   28.215
p   17.308   16.152   35.187
p   17.387   13.658   42.271
p   17.860   11.676   49.303
p   17.776   10.233   57.241
p   17.518    9.736   64.320

p    6.497   15.883    0.654
p    5.514   17.551    7.187
p    4.259   17.445   14.038
p    3.730   16.360   20.769
p    4.290   14.469   28.012
p    4.561   12.378   35.128

p    5.218   10.177   42.559
p    5.665    8.678   49.919
p    5.922    7.696   56.896
p    6.457    7.002   64.205

p   -0.001    0.100   -0.003
p   -2.902   -0.033    6.720
p   -4.867    0.143   13.651
p   -6.164    0.450   21.174
p   -6.262    0.222   27.976
p   -5.751    0.168   34.567
p   -4.373    0.148   41.807
p   -2.803    0.072   49.203
p   -0.973    0.062   56.416
p    1.138   -0.064   64.038
check
spline
new reference point ILGP UV    14.1637697    3.0714359
new reference point CLGP UV    11.0137281    6.1029201
new reference point OLGP UV     7.2531962    2.9864457
new reference point IBH UV     21.9109440    7.5281553
new reference point OBH UV      0.1064249    7.5152535
new reference point FGAP UV    11.0000000    0.0000000
new reference point RGAP UV     0.0000000    4 5000000
new reference point BH UV      0 0000000    7 5217042
    $( Model Last $)
size 5d
Enable thickness
```

DIGITISED LAST DATA (C&J CLARKS SHOEMASTER)

LAST-H6028

```
$( release_3.30 $)

     Disable thickness
new model 5d
units mm
position
      0.096        -0.101 100.000
      0.096        -0.101         -0.202
    244.544        -0.498         -0.099
pitch     -0.5
new sole u 11 by v 4

p     2.132    8.167    0.087
p     0.876    4.787   -0.003
p     0.096   -0.101   -0.202
p    -0.081   -4.799   -0.308
p     0.645   -9.611   -0.127

p     5.012   12.921    0.357
p     4.598    6.629   -0.650
p     4.180   -0.565   -0.858
p     3.370   -7.453   -0.860
p     2.872  -14.448    0.134

p    16.153   21.244    0.822
p    15.467   10.756   -0.588
p    14.670   -1.132   -1.100
p    14.503  -11.731   -1.018
p    13.919  -24.325    0.266

p    33.206   23.871    1.397
p    32.265   10.388   -0.516
p    32.252   -2.412   -1.240
p    31.328  -16.900   -0.755
p    30.546  -29.792    1.032

p    57.872   21.177    1.660
p    56.828    7.495   -0.252
p    56.817   -5.505   -0.577
p    55.803  -19.292   -0.189
p    55.015  -32.484    1.497

p    83.931   18.562    1.303
p    82.995    5.679   -1.009
p    82.474   -7.412   -1.927
p    82.448  -21.915   -1.554
p    81.975  -34.412    0.329

p   119.819   20.597   -2.577
p   119.013    3.913   -5.598
p   118.466  -10.779   -6.519
p   118.538  -25.683   -5.848
p   118.352  -38.985   -3.970

p   153.133   29.371   -5.010
p   152.204   11.589   -8.432
p   151.578   -8.001   -9.461
p   151.592  -26.806   -8.496
p   151.355  -43.909   -5.825

p   185.094   32.361   -4.536
p   185.392   15.759   -7.372
p   185.381   -2.942   -8.307
p   184.989  -21.939   -7.537
p   184.616  -41.140   -5.168

p   212.759   27.816   -2.217
p   212.684   12.920   -5.045
p   212.050   -1.471   -5.364
p   212.206  -17.076   -5.095
p   211.977  -32.878   -3.422

p   236.511   16.532   -0.259
p   236.346    7.336   -1.674
p   236.317   -0.464   -1.989
p   235.882   -8.858   -2.099
p   235.939  -18.862   -0.918

p   241.718   10.448   -0.041
p   243.832    5.014   -0.079
p   244.544   -0.498   -0.099
p   243.765   -5.286   -0.298
p   241.046  -12.543   -0.475
check
spline
units mm
position
    0.057     0.303    63.849
    0.096    -0.101    -0.202
  244.544    -0.498    -0.099
pitch      -0.5
new upper u 22 by v 9

p     0.096   -0.101   -0.202
p    -2.991    0.274    6.346
p    -5.242    0.251   12.887
p    -6.562    0.584   19.822
p    -6.977    0.532   27.613
p    -6.177    0.523   35.168
p    -4.978    0.363   42.747
p    -3.267    0.299   50.101
p    -1.733    0.327   57.042
p     0.057    0.303   63.849

p     2.872  -14.448    0.134
p     0.766  -14.888    6.132
p    -0.311  -15.254   13.193
p    -0.609  -14.712   20.679
p    -0.295  -13.075   27.976
p     0.414  -10.836   35.383
p     1.395   -8.688   43.307
p     2.508   -7.251   50.651
p     3.130   -6.318   57.778
p     4.010   -5.805   63.824

p    13.919  -24.325    0.266
p    13.456  -26.104    6.518
p    13.074  -25.668   13.701
p    12.980  -22.627   21.151
p    13.397  -18.790   28.412
p    14.928  -15.560   35.443
p    15.827  -12.617   43.048
p    15.521  -10.672   50.707
p    15.387   -9.753   56.992
p    15.110   -9.719   64.088

p    30.546  -29.792    1.032
p    29.936  -30.817    7.284
p    29.681  -30.191   13.969
p    29.403  -26.755   21.101
p    30.047  -22.628   27.868
p    30.665  -18.392   35.132
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p	30.881	-15.255	42.396
p	30.938	-13.097	50.772
p	30.583	-12.070	57.444
p	30.206	-11.936	64.533
p	55.015	-32.484	1.497
p	55.510	-34.238	8.409
p	54.183	-33.321	14.531
p	51.910	-29.384	21.547
p	50.563	-24.858	28.100
p	49.236	-20.739	34.262
p	47.214	-16.985	42.196
p	45.510	-14.739	49.775
p	44.047	-13.608	56.587
p	42.724	-13.057	64.519
p	81.975	-34.412	0.329
p	81.109	-36.403	7.208
p	79.666	-35.580	13.626
p	76.073	-31.935	20.978
p	72.644	-27.613	27.124
p	69.678	-22.678	33.984
p	66.800	-18.839	41.070
p	63.389	-16.388	48.754
p	59.544	-14.826	57.034
p	56.702	-14.165	65.283
p	118.352	-38.985	-3.970
p	117.002	-40.550	2.585
p	113.331	-39.814	9.487
p	107.687	-36.048	17.729
p	101.369	-30.391	25.499
p	94.414	-25.555	32.049
p	87.258	-20.884	40.494
p	83.479	-18.444	47.558
p	76.560	-16.351	57.167
p	69.893	-14.877	65.798
p	151.355	-43.909	-5.825
p	150.837	-46.138	0.885
p	149.062	-45.803	7.896
p	144.055	-41.852	15.467
p	133.903	-35.212	21.913
p	123.362	-27.541	30.021
p	112.843	-22.779	37.684
p	101.937	-19.286	46.954
p	92.695	-16.782	56.931
p	82.257	-15.644	68.674
p	184.616	-41.140	-5.168
p	184.531	-43.473	1.926
p	183.066	-43.642	8.762
p	178.010	-40.909	15.353
p	164.883	-34.375	21.241
p	151.843	-28.438	27.346
p	136.574	-22.952	35.845
p	120.249	-19.010	47.222
p	104.373	-16.352	59.548
p	90.928	-15.308	71.333
p	211.977	-32.878	-3.422
p	211.433	-34.565	4.591
p	210.453	-34.265	9.842
p	203.457	-32.151	15.239
p	190.659	-27.965	18.685
p	175.568	-23.543	23.808
p	156.101	-19.318	34.011
p	136.225	-16.119	48.117
p	118.239	-14.519	62.454
p	102.045	-13.555	75.096
p	235.939	-18.862	-0.918
p	235.518	-19.481	5.687
p	234.506	-19.269	11.539
p	228.609	-18.192	15.111
p	210.678	-15.925	17.119
p	187.627	-13.073	23.150
p	165.601	-11.325	34.365
p	145.683	-11.213	49.228
p	126.296	-10.376	65.409
p	107.719	-10.280	79.542
p	244.544	-0.498	-0.099
p	243.785	-0.071	6.761
p	242.479	0.039	12.499
p	237.189	-0.088	15.926
p	217.592	-1.132	17.206
p	191.834	-1.876	23.262
p	169.898	-2.826	34.633
p	150.215	-3.291	50.722
p	130.542	-3.859	66.613
p	110.539	-4.852	81.192
p	236.511	16.532	-0.259
p	235.837	18.127	5.793
p	234.630	17.937	11.542
p	228.911	16.220	15.477
p	208.323	13.509	18.439
p	188.143	11.266	25.020
p	167.187	8.421	36.780
p	145.620	6.252	52.500
p	127.234	4.151	66.786
p	108.596	2.333	80.152
p	212.759	27.816	-2.217
p	210.513	29.633	3.828
p	206.115	29.879	11.201
p	197.201	28.500	16.863
p	184.826	25.911	21.662
p	172.671	22.349	27.994
p	155.270	17.780	38.773
p	134.635	12.362	52.000
p	117.419	8.734	64.975
p	102.754	6.185	77.064
p	185.094	32.361	-4.536
p	183.175	34.544	1.980
p	177.242	34.804	9.973
p	168.548	33.554	17.146
p	158.286	30.693	23.665
p	147.295	26.642	30.669
p	136.338	20.914	38.908
p	120.480	14.563	50.805
p	106.627	10.508	62.665
p	95.826	7.932	73.657
p	153.133	29.371	-5.010
p	150.249	32.090	1.577
p	145.247	32.838	9.009
p	138.824	31.995	16.796
p	131.404	29.351	24.464
p	122.762	24.816	32.503

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p  115.776  20.559  39.524
p  105.013  15.169  49.770
p   94.858  11.576  59.915
p   87.553   9.462  69.182

p  119.819  20.597  -2.577
p  117.686  24.782   3.689
p  115.626  27.213  10.444
p  112.227  28.058  17.859
p  107.385  26.820  26.038
p  102.914  23.655  32.872
p   97.942  19.791  39.691
p   90.839  15.476  48.910
p   84.448  12.456  57.942
p   78.673  10.030  66.695

p   83.931  18.562   1.303
p   83.760  23.000   7.026
p   82.472  25.740  14.317
p   80.950  26.055  20.340
p   78.606  24.980  26.746
p   75.926  21.716  33.776
p   73.494  18.535  39.917
p   69.963  15.191  47.905
p   65.907  12.756  56.349
p   62.425  11.130  65.309

p   57.872  21.177   1.660
p   58.082  25.157   7.822
p   56.919  26.688  14.642
p   55.717  26.196  20.297
p   53.986  24.114  26.454
p   52.099  20.452  33.634
p   50.572  17.369  39.721
p   49.284  14.242  48.826
p   47.679  12.486  56.386
p   46.154  11.339  64.340

p   33.206  23.871   1.397
p   33.140  26.401   7.974
p   32.710  26.418  14.161
p   32.589  25.032  20.190
p   32.166  22.345  26.228
p   31.815  18.869  32.785
p   31.694  15.617  40.653
p   31.260  13.270  48.787
p   31.016  11.727  57.117
p   30.942  10.860  64.140

p   16.153  21.244   0.822
p   15.864  23.310   7.013
p   15.519  23.233  13.507
p   15.397  21.747  19.538
p   15.931  19.275  26.424
p   15.764  16.104  33.286
p   15.639  13.154  41.248
p   15.631  11.298  48.895
p   15.477  10.058  57.423
p   15.620   9.885  64.145

p    5.012  12.921   0.357
p    3.847  15.527   6.922
p    2.288  15.556  13.649
p    1.974  15.168  19.549
p    1.977  13.708  26.989
p    2.480  11.747  34.465
p    2.960   9.694  42.341
p    3.153   8.238  49.991
p    3.373   7.272  57.133
p    4.715   7.098  63.918

p    0.096  -0.101  -0.202
p   -2.991   0.274   6.346
p   -5.242   0.251  12.887
p   -6.562   0.584  19.822
p   -6.977   0.532  27.613
p   -6.177   0.523  35.168
p   -4.978   0.363  42.747
p   -3.267   0.299  50.101
p   -1.733   0.327  57.042
p    0.057   0.303  63.849
check
spline
new reference point ILGP UV    14.1399317   3.0092118
new reference point CLGP UV    11.0165777   5.9744220
new reference point OLGP UV     7.3213096   3.0271463
new reference point IBH UV     21.8958244   7.2775540
new reference point OBH UV      0.0817914   7.2712936
     $( Model Last $)
size 5d
Enable thickness
```

APPENDIX III-II

DIGITISED FOOT DATA (BUSM CRISPIN)

```
VALIB CYBVAX
dcr
chrysler/poly001.ASC
    53
POINTSET            41
     67.698000      1.182000      0.000000
     20.502000      4.358000      0.000000
     98.664000     26.437000      0.000000
     69.172000     27.947000      0.000000
     30.586000     45.345000      0.000000
     -5.441000     51.769000      0.000000
    -27.378000     45.564000      0.000000
    -71.737000     98.737000      0.000000
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   -261.994000    176.717000      0.000000
   -297.373000    240.808000      0.000000
   -309.863000    320.872000      0.000000
   -308.309000    409.140000      0.000000
   -295.187000    437.632000      0.000000
   -156.127000    582.674000      0.000000
    -76.341000    621.747000      0.000000
    -11.700000    670.321000      0.000000
     11.978000    686.232000      0.000000
     88.604000    721.625000      0.000000
    175.709000    704.730000      0.000000
    201.085000    701.265000      0.000000
    288.119000    678.766000      0.000000
    364.528000    631.381000      0.000000
    383.186000    613.225000      0.000000
    484.179000    451.504000      0.000000
    492.541000    371.156000      0.000000
    529.441000    293.474000      0.000000
    535.005000    260.940000      0.000000
    528.757000    171.804000      0.000000
    508.278000     89.623000      0.000000
    499.420000     79.100000      0.000000
    456.503000      7.968000      0.000000
    383.291000    -47.062000      0.000000
    377.087000    -59.725000      0.000000
    301.293000    -92.115000      0.000000
    218.342000   -106.493000      0.000000
    226.172000   -115.240000      0.000000
    -63.191000     72 693000      0.000000
    119.042000   -141 868000      0.000000
    -88.155000    112 834000      0.000000
     67.698000      1.182000      0.000000
POINTSET            25
   -450.412000      0.000000    122.500000
   -463.193000     48.684000    122.500000
   -518.763000    324.159000    122.500000
   -470.047000    540.728000    122.500000
   -329.586000    706.800000    122.500000
   -131.351000    829.317000    122.500000
    -44.804000    854.918000    122.500000
     46.346000    884.335000    122.500000
     93.778000    892.237000    122.500000
    307.507000    801.083000    122.500000
    487.151000    670.505000    122.500000
    616.113000    481 360000    122.500000
    665.336000    399.774000    122.500000
    704.242000    313.549000    122.500000
    709.310000    272.279000    122.500000
    666.651000     46.617000    122.500000
    616.876000    -43.136000    122.500000
    564.720000   -120.035000    122.500000
    550.810000   -137.332000    122.500000
    367.772000   -257.517000    122.500000
    170.031000   -306.744000    122.500000
   -140.101000   -274.964000    122.500000
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   -415.027000    -80.673000    122.500000
   -450.412000      0.000000    122.500000
POINTSET            28
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   -667.709000    141.926000    245.833000
   -681.805000    459.884000    245.833000
   -604.069000    670.887000    245.833000
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   -254.749000    950.735000    245.833000
   -175.068000    992.861000    245.833000
    -90.271000   1031.806000    245.833000
    -54.445000   1038.872000    245.833000
     36.730000   1051.801000    245.833000
    126.120000   1027.166000    245.833000
    158.507000   1000.772000    245.833000
    349.829000    865.857000    245.833000
    533.147000    733.813000    245.833000
    676.305000    567.488000    245.833000
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   -250.114000   -451.218000    245.833000
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   -863.064000    604.324000    491.667000
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    200.117000   1134.918000    491.667000
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    309.529000    952.632000    491.667000
    327.394000    950.820000    491.667000
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    679.996000    704 157000    491.667000
    686.715000    686 715000    491.667000
    765.352000    475.245000    491.667000
    790.530000    256.859000    491.667000
    785.155000     27.418000    491.667000
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    414.024000   -476.281000    491.667000
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    640.600000  -1509.159000    491.667000
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   -243.861000   -670.004000    491.667000
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683.458000	906.980000	1475.000000
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-1290.943000	972.795000	1966.667000
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-277.816000	1976.764000	1966.667000
33.158000	1899.629000	1966.667000
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586.034000	1610.115000	1966.667000
801.067000	1387.489000	1966.667000
933.983000	1113.078000	1966.667000
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1063.798000	187.576000	1966.667000
953.408000	-100.207000	1966.667000
814.099000	-362.460000	1966.667000
744.810000	-465.409000	1966.667000
649.057000	-544.624000	1966.667000
651.648000	-586.747000	1966.667000
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1213.495000	-1799.080000	1966.667000
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1154.525000	-2082.818000	1966.667000
1130.371000	-2125.918000	1966.667000
1044.016000	-2238.900000	1966.667000
939.478000	-2325.289000	1966.667000
898.042000	-2339.481000	1966.667000
878.866000	-3064.971000	1966.667000
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781.802000	-3386.356000	1966.667000
574.260000	-3625.734000	1966.667000
455.795000	-3712.154000	1966.667000
331.909000	-3793.738000	1966.667000
266.093000	-3805.301000	1966.667000
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792.933000	1780.956000	2458.333000
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675.587000	-3831.442000	2950.833000
628.377000	-4471.138000	2950.833000
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416.814000	-4764.201000	2950.833000
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84.437000	-4837.391000	2950.833000
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1446.201000	674.374000	3442.500000
1367.321000	340.911000	3442.500000
1297.274000	205.468000	3442.500000
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688.940000	-159.054000	3442.500000
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1365.709000	-1686.510000	3442.500000
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1181.230000	2130.995000	3442.500000
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297.064000	2113.717000	3934.167000
625.025000	2044.365000	3934.167000
922.206000	1890.803000	3934.167000
1229.400000	1692.124000	3934.167000
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1463.355000	419.610000	3934.167000
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1177.581000	103.025000	3934.167000
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91.757000	-5256.738000	3934.167000
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-179.095000	-5128.622000	3934.167000
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POINTSET	51	
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396.749000	2250.074000	4917.500000
817.544000	2129.776000	4917.500000
1184.459000	1895.530000	4917.500000
1489.186000	1596.957000	4917.500000
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1729.152000	806.317000	4917.500000
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1503.943000	0.000000	4917.500000
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1394.321000	-1212.065000	4917.500000
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1175.905000	-3063.338000	4917.500000
1056.446000	-3251.406000	4917.500000
1011.675000	-3309.040000	4917.500000
1126.453000	-4203.981000	4917.500000
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990.211000	-5094.195000	4917.500000
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768.349000	-5467.084000	4917.500000
723.436000	-5891.913000	4917.500000
528.702000	-6043.095000	4917.500000
321.709000	-6138.574000	4917.500000
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-324.867000	-6198.828000	4917.500000
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-572.640000	-3615.509000	4917.500000
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-1268.200000	-2385.137000	4917.500000
-1340.201000	-1986.930000	4917.500000
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-1377.158000	0.000000	4917.500000
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1351.864000	1930.662000	5410.000000
1638.551000	1582.330000	5410.000000
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648.145000	-6166.684000	5410.000000
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POINTSET	50	
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1138.709000	-4249.718000	5901.667000
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1682.384000	1935.361000	6393.333000
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1687.858000	-2410.511000	6393.333000
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1000.801000	-5675.824000	6393.333000
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755.638000	-6154.177000	6393.333000
545.173000	-6231.359000	6393.333000
327.700000	-6252.879000	6393.333000
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2018.272000	-2089.981000	6885.000000
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1574.990000	-3091.091000	6885.000000
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175.690000	2512.479000	7376.667000
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624.267000	2503.800000	7376.667000

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2676.074000	-921.446000	7376.667000
2545.679000	-1411.093000	7376.667000
2344.985000	-1898.931000	7376.667000
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1704.535000	-3345.338000	7376.667000
1462.695000	-3810.451000	7376.667000
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POINTSET	48	
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348.157000	2477.265000	7869.167000
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1320.614000	2113.425000	7869.167000
1734.794000	1796.432000	7869.167000
2119.385000	1429.543000	7869.167000
2469.020000	997.549000	7869.167000
2736.017000	531.828000	7869.167000
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843.585000	-6002.419000	7869.167000
647.463000	-6160.194000	7869.167000
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POINTSET	47	
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3044.978000	-1230.251000	8360.833000
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POINTSET	48	
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744.332000	2434.601000	8852.500000
967.268000	2394.071000	8852.500000
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1934.928000	1742.217000	8852.500000
2364.215000	1364.980000	8852.500000
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3255.862000	-1057.894000	8852.500000
3112.777000	-1586.039000	8852.500000
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665.420000	-6331.051000	8852.500000
448.208000	-6409.675000	8852.500000
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POINTSET	50	
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0.000000	2308.165000	9344.167000
549.776000	2381.342000	9344.167000
779.962000	2400.476000	9344.167000
1009.834000	2379.021000	9344.167000
1098.780000	2356.340000	9344.167000
1593.535000	2114.693000	9344.167000
2025.299000	1760.566000	9344.167000
2435.557000	1406.169000	9344.167000
2861.501000	1041.501000	9344.167000
3182.307000	561.127000	9344.167000
3441.958000	60.080000	9344.167000
3519.384000	-494.617000	9344.167000
3455.466000	-1056.442000	9344.167000
3292.033000	-1605.632000	9344.167000
3064.184000	-2145.565000	9344.167000
2813.714000	-2623.831000	9344.167000
2528.473000	-3122.405000	9344.167000
2242.875000	-3589.350000	9344.167000
2003.560000	-4107.907000	9344.167000
1757.102000	-4577.407000	9344.167000
1474.765000	-5143.118000	9344.167000
1189.706000	-5597.127000	9344.167000
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856.740000	-6096.025000	9344.167000
657.628000	-6256.912000	9344.167000
443.901000	-6348.076000	9344.167000
333.947000	-6372.084000	9344.167000
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653.364000	-6216.343000	9344.167000
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1118.486000	-5754.113000	9344.167000
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1066.016000	-2185.658000	9344.167000
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POINTSET	45	
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-1015.976000	88.886000	9835.833000
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-983.008000	1213.914000	9835.833000
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-411.958000	2119.342000	9835.833000
118.152000	2254.477000	9835.833000
672.419000	2345.004000	9835.833000
1224.618000	2303.172000	9835.833000
1753.645000	2089.913000	9835.833000
2180.016000	1765.342000	9835.833000
2613.869000	1389.819000	9835.833000
3050.542000	991.181000	9835.833000
3390.243000	536.962000	9835.833000
3641.536000	0.000000	9835.833000
3721.854000	-589.484000	9835.833000
3653.845000	-1117.093000	9835.833000
3493.942000	-1629.252000	9835.833000
3258.466000	-2116.072000	9835.833000
2971.931000	-2583.460000	9835.833000
2654.454000	-3053.600000	9835.833000
2385.854000	-3537.174000	9835.833000
2131.212000	-4008.227000	9835.833000
1827.628000	-4523.539000	9835.833000
1539.891000	-5036.757000	9835.833000
1182.034000	-5561.032000	9835.833000
1022.237000	-5797.394000	9835.833000
842.943000	-5997.850000	9835.833000
647.905000	-6164.407000	9835.833000
437.553000	-6257.294000	9835.833000
329.126000	-6280.100000	9835.833000
-218.727000	-6263.509000	9835.833000
-436.411000	-6240.965000	9835.833000
-930.158000	-5872.786000	9835.833000
-1266.505000	-5079.676000	9835.833000
-1101.880000	-4112.274000	9835.833000
-1071.163000	-3296.701000	9835.833000
-1074.985000	-2660.682000	9835.833000
-1001.500000	-2053.379000	9835.833000
-985.133000	-1516.972000	9835.833000
-987.249000	-987.249000	9835.833000
-1001.378000	-445.842000	9835.833000
-1004.794000	0.000000	9835.833000
POINTSET	46	
-993.655000	0.000000	10327.500000
-998.566000	140.339000	10327.500000
-982.496000	916.193000	10327.500000
-870.211000	1448.275000	10327.500000
-540.190000	1883.867000	10327.500000
-357.457000	2027.239000	10327.500000
-150.476000	2151.909000	10327.500000
-76.169000	2181.200000	10327.500000
483.329000	2273.884000	10327.500000
1047.325000	2352.330000	10327.500000
1574.687000	2248.886000	10327.500000
2062.649000	1991.877000	10327.500000
2516.654000	1634.334000	10327.500000
2936.632000	1246.526000	10327.500000
3367.968000	839.729000	10327.500000
3670.410000	385.776000	10327.500000
3914.979000	-136.714000	10327.500000
3970.631000	-700.129000	10327.500000
3863.988000	-1255.486000	10327.500000
3649.168000	-1779.818000	10327.500000
3334.203000	-2248.948000	10327.500000
3018.337000	-2717.723000	10327.500000
2674.431000	-3187.263000	10327.500000
2399.851000	-3695.447000	10327.500000
2056.009000	-4215.443000	10327.500000
1723.709000	-4735.851000	10327.500000
1400.541000	-5226.888000	10327.500000
1105.123000	-5685.364000	10327.500000
934.463000	-5899.968000	10327.500000
744.267000	-6061.568000	10327.500000
642.896000	-6116.750000	10327.500000
108.549000	-6218.777000	10327.500000
-108.322000	-6205.747000	10327.500000
-324.419000	-6190.291000	10327.500000
-431.066000	-6164.529000	10327.500000
636.823000	-6058.969000	10327.500000
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1276.495000	-4763.943000	10327.500000
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-1064.457000	-3276.063000	10327.500000
-1000.360000	-2606.028000	10327.500000
-999.839000	-2049.974000	10327.500000
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993.655000	0.000000	10327.500000
POINTSET	42	
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-965.128000	838.973000	10820.000000
-798.381000	1382.836000	10820.000000
-452.711000	1815.723000	10820.000000
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1683.114000	2233.568000	10820.000000
2207.443000	1987.590000	10820.000000
2645.108000	1652.847000	10820.000000
3090.497000	1248.642000	10820.000000
3503.056000	873.410000	10820.000000
3890.964000	408.957000	10820.000000
4148.556000	-72.413000	10820.000000
4222.032000	-668.704000	10820.000000
4130.426000	-1262.798000	10820.000000
3886.989000	-1812.533000	10820.000000
3540.662000	-2299.333000	10820.000000
3161.699000	-2748.423000	10820.000000
2793.289000	-3213.312000	10820.000000
2467.957000	-3658.896000	10820.000000
2114.313000	-4149.572000	10820.000000
1786.488000	-4653.961000	10820.000000
1463.321000	-5103.207000	10820.000000
1102.009000	-5669.345000	10820.000000
931.357000	-5880.360000	10820.000000
741.217000	-6036.729000	10820.000000
640.798000	-6096.788000	10820.000000
0.000000	-6158.561000	10820.000000
-320.221000	-6110.172000	10820.000000

-629.072000	-5985.224000	10820.000000
-1062.325000	-5465.188000	10820.000000
-1275.328000	-4759.589000	10820.000000
-1153.989000	-4024.436000	10820.000000
-1083.015000	-3145.304000	10820.000000
-989.798000	-2578.513000	10820.000000
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-978.266000	-880.835000	10820.000000
-972.008000	-315.825000	10820.000000
-982.379000	0.000000	10820.000000
POINTSET	41	
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-826.284000	1137.282000	11311.667000
-490.785000	1605.287000	11311.667000
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532.245000	2134.719000	11311.667000
1113.447000	2282.905000	11311.667000
1693.971000	2247.976000	11311.667000
2244.109000	2020.604000	11311.667000
2703.311000	1689.216000	11311.667000
3133.978000	1330.295000	11311.667000
3596.122000	963.578000	11311.667000
4010.224000	563.600000	11311.667000
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4417.875000	-1101.500000	11311.667000
4219.965000	-1704.977000	11311.667000
3867.548000	-2232.930000	11311.667000
3447.052000	-2693.132000	11311.667000
3033.668000	-3141.455000	11311.667000
2618.535000	-3604.104000	11311.667000
2230.828000	-4024.520000	11311.667000
1907.693000	-4494.243000	11311.667000
1530.545000	-5006.188000	11311.667000
1177.963000	-5541.882000	11311.667000
1016.393000	-5764.249000	11311.667000
833.914000	-5933.607000	11311.667000
736.546000	-5998.684000	11311.667000
106.452000	-6098.650000	11311.667000
-211.260000	-6049.694000	11311.667000
-520.830000	-5953.117000	11311.667000
-971.455000	-5509.395000	11311.667000
-1219.808000	-4892.383000	11311.667000
-1202.967000	-4195.244000	11311.667000
-1196.579000	-3475.116000	11311.667000
-1139.475000	-2820.300000	11311.667000
-1052.263000	-2157.458000	11311.667000
-1013.014000	-1559.905000	11311.667000
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POINTSET	43	
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1856.778000	2212.821000	11803.333000
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3689.633000	-2680.675000	11803.333000
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2796.684000	-3579.592000	11803.333000
2304.799000	-3992.029000	11803.333000
1908.762000	-4496.761000	11803.333000
1523.863000	-4984.332000	11803.333000
1169.384000	-5501.521000	11803.333000
1006.787000	-5709.774000	11803.333000
825.877000	-5876.423000	11803.333000
728.697000	-5934.758000	11803.333000
421.788000	-6031.850000	11803.333000
105.381000	-6037.258000	11803.333000
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-513.678000	-5871.367000	11803.333000
-704.401000	-5736.882000	11803.333000
-1102.226000	-5185.563000	11803.333000
-1239.256000	-4624.966000	11803.333000
-1213.757000	-3970.019000	11803.333000
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-993.496000	-211.174000	11803.333000
-979.432000	0.000000	11803.333000
POINTSET	42	
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159.607000	1824.321000	12295.000000
710.269000	2062.770000	12295.000000
1292.496000	2238.670000	12295.000000
1898.919000	2184.456000	12295.000000
2485.300000	1941.729000	12295.000000
3049.199000	1621.288000	12295.000000
3622.545000	1318.499000	12295.000000
4108.325000	948.482000	12295.000000
4562.899000	479.580000	12295.000000
4789.759000	-83.606000	12295.000000
4836.747000	-679.760000	12295.000000
4780.081000	-1280.819000	12295.000000
4572.988000	-1847.607000	12295.000000
4238.245000	-2349.298000	12295.000000
3830.605000	-2783.097000	12295.000000
3360.069000	-3244.781000	12295.000000
2867.171000	-3669.811000	12295.000000
2333.761000	-4042.193000	12295.000000
1909.692000	-4498.953000	12295.000000
1511.800000	-4944.875000	12295.000000
1152.573000	-5422.432000	12295.000000
992.174000	-5626.898000	12295.000000
814.886000	-5798.219000	12295.000000
719.813000	-5862.404000	12295.000000
417.876000	-5975.905000	12295.000000
104.488000	5986.126000	12295.000000
-206.398000	-5910.466000	12295.000000
-508.480000	-5811.955000	12295.000000
-696.852000	-5675.408000	12295.000000
-1096.722000	-5159.673000	12295.000000
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-1227.287000	-4014.276000	12295.000000
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-1077.746000	-904.337000	12295.000000
-972.424000	0.000000	12295.000000
POINTSET	43	
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-581.514000	1093.669000	12786.667000
161.586000	1537.385000	12786.667000
364.355000	1874.444000	12786.667000
948.583000	2130.552000	12786.667000
1175.179000	2210.190000	12786.667000
1473.794000	2269.443000	12786.667000
1532.997000	2272.761000	12786.667000
2153.145000	2153.145000	12786.667000
2707.978000	1896.147000	12786.667000
3306.972000	1612.918000	12786.667000
3903.309000	1344.017000	12786.667000
4409.189000	937.202000	12786.667000
4838.160000	423.284000	12786.667000
5020.951000	-175.335000	12786.667000
5034.390000	-797.369000	12786.667000
4945.159000	-1418.001000	12786.667000
4704.058000	-1996.754000	12786.667000
4352.755000	2513.065000	12786.667000
3898.885000	-2938.021000	12786.667000
3473.278000	-3354.106000	12786.667000
2931.971000	-3752.752000	12786.667000
2363.165000	-4093.121000	12786.667000
1902.330000	-4481.610000	12786.667000
1428.757000	-4982.669000	12786.667000
1062.075000	-5463.901000	12786.667000
893.955000	-5644.211000	12786.667000
712.295000	-5901.175000	12786.667000
615.828000	-5859.210000	12786.667000
311.126000	-5936.630000	12786.667000
0.000000	-5905.808000	12786.667000
-305.629000	-5831.756000	12786.667000
-598.232000	-5691.800000	12786.667000
-1015.387000	-5223.711000	12786.667000
-1245.585000	-4648.585000	12786.667000
-1335.042000	-3877.245000	12786.667000
-1307.518000	-3236.219000	12786.667000
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-1214.318000	-1943.315000	12786.667000
-1154.304000	-1327.875000	12786.667000
-1106.404000	-718.507000	12786.667000
-979.318000	0.000000	12786.667000
POINTSET	42	
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-433.603000	1129.574000	13279.167000
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526.114000	1963.483000	13279.167000
759.109000	2085.635000	13279.167000
985.302000	2213.025000	13279.167000
1106.516000	2268.695000	13279.167000
1748.930000	2320.908000	13279.167000
2376.976000	2140.239000	13279.167000
2948.610000	1842.496000	13279.167000
3626.511000	1614.627000	13279.167000
4220.776000	1290.421000	13279.167000
4696.607000	912.928000	13279.167000
5113.043000	357.539000	13279.167000
5282.403000	-276.839000	13279.167000
5259.184000	-927.336000	13279.167000
5088.337000	-1555.661000	13279.167000
4842.350000	-2155.953000	13279.167000
4415.896000	-2653.338000	13279.167000
3925.612000	-3067.024000	13279.167000
3449.584000	-3449.584000	13279.167000
2888.201000	-3832.772000	13279.167000
2333.586000	-4209.902000	13279.167000
1766.356000	-4601.515000	13279.167000
1267.999000	-5085.664000	13279.167000
1044.100000	-5371.430000	13279.167000
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792.655000	-5640.032000	13279.167000
507.088000	-5796.040000	13279.167000
204.104000	-5844.769000	13279.167000
-101.429000	-5810.874000	13279.167000
-401.790000	-5745.867000	13279.167000
-1203.885000	-4828.519000	13279.167000
-1372.176000	-4223.125000	13279.167000
-1366.789000	-3382.920000	13279.167000
-1329.329000	-2725.529000	13279.167000
-1277.021000	-2043.660000	13279.167000
-1211.274000	-1393.411000	13279.167000
-1154.431000	-778.673000	13279.167000
-1029.835000	-181.588000	13279.167000
-971.962000	0.000000	13279.167000
POINTSET	43	
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-624.992000	771.801000	13770.833000
-301.107000	1304.238000	13770.833000
182.380000	1735.230000	13770.833000
723.953000	2102.512000	13770.833000
946.607000	2230.068000	13770.833000
1202.399000	2359.841000	13770.833000
1320.898000	2382.963000	13770.833000
1953.766000	2328.407000	13770.833000
2561.995000	2074.663000	13770.833000
3158.771000	1823.717000	13770.833000
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4445.804000	1359.219000	13770.833000
5005.411000	972.953000	13770.833000
5247.261000	737.454000	13770.833000
5482.512000	479.658000	13770.833000
5659.188000	-197.623000	13770.833000
5577.130000	-883.331000	13770.833000
5328.879000	-1528.031000	13770.833000
5008.367000	-2125.925000	13770.833000
4576.576000	-2642.288000	13770.833000
4086.705000	-3079.553000	13770.833000
3580.828000	-3457.966000	13770.833000
2998.110000	-3837.406000	13770.833000
2415.636000	-4184.004000	13770.833000
1839.124000	-4551.991000	13770.833000
1332.464000	-4972.822000	13770.833000
864.342000	-5457.240000	13770.833000
592.086000	-5633.320000	13770.833000
300.051000	-5725.305000	13770.833000
0.000000	-5713.713000	13770.833000
-296.954000	-5666.215000	13770.833000
-394.779000	-5645.608000	13770.833000
-925.461000	-5248.548000	13770.833000
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-1417.720000	-4117.359000	13770.833000
-1457.229000	-3433.016000	13770.833000
-1392.925000	-2733.768000	13770.833000
-1342.571000	-2067.378000	13770.833000
-1287.540000	-1429.959000	13770.833000
-1207.948000	-784.451000	13770.833000
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-1001.067000	0.000000	13770.833000
POINTSET	46	
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-724.224000	776.635000	14262.500000
-379.483000	1323.413000	14262.500000
122.070000	1745.677000	14262.500000
653.633000	2137.939000	14262.500000
876.174000	2282.511000	14262.500000
1165.446000	2389.518000	14262.500000
1280.364000	2408.015000	14262.500000
1950.972000	2325.078000	14262.500000
2561.848000	2074.544000	14262.500000
3223.665000	1861.184000	14262.500000
3925.870000	1666.433000	14262.500000
4623.087000	1413.420000	14262.500000
5246.613000	1211.276000	14262.500000
5470.985000	1063.452000	14262.500000
5746.869000	910.215000	14262.500000
5829.113000	819.228000	14262.500000
6023.906000	527.023000	14262.500000
6098.325000	212.958000	14262.500000
6077.867000	-425.006000	14262.500000
5908.035000	-1041.746000	14262.500000
5530.293000	-1690.780000	14262.500000
5077.828000	-2260.795000	14262.500000
4592.051000	-2759.183000	14262.500000
4096.446000	-3200.494000	14262.500000
3502.159000	-3626.592000	14262.500000
2857.629000	-3933.188000	14262.500000
2276.614000	-4281.688000	14262.500000
1685.998000	-4632.240000	14262.500000
1171.132000	-5072.731000	14262.500000
932.474000	-5288.323000	14262.500000
671.657000	-5470.209000	14262.500000
580.372000	-5521.872000	14262.500000
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-387.245000	-5537.868000	14262.500000
-668.199000	-5442.044000	14262.500000
-755.110000	-5372.885000	14262.500000
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-1412.472000	-2175.016000	14262.500000
-1371.435000	-1523.133000	14262.500000
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-1140.452000	-221.681000	14262.500000
-1057.978000	0.000000	14262.500000
POINTSET	46	
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-395.040000	1377.667000	14754.167000
127.675000	1825.841000	14754.167000
682.822000	2233.411000	14754.167000
960.747000	2377.933000	14754.167000
1246.856000	2447.093000	14754.167000
1359.613000	2452.807000	14754.167000
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2703.521000	2037.249000	14754.167000
3431.311000	1824.460000	14754.167000
4119.278000	1664.296000	14754.167000
4993.420000	1526.642000	14754.167000
5727.870000	1322.383000	14754.167000
6015.025000	1169.202000	14754.167000
6308.570000	999.179000	14754.167000
6423.102000	902.708000	14754.167000
6656.797000	232.460000	14754.167000
6727.932000	-117.437000	14754.167000
6752.122000	-472.154000	14754.167000
6666.871000	-818.589000	14754.167000
6484.044000	-1143.312000	14754.167000
5971.057000	-1599.940000	14754.167000
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4944.966000	-2629.285000	14754.167000
4374.005000	-3062.711000	14754.167000
3771.731000	-3517.196000	14754.167000
3119.593000	-3852.376000	14754.167000
2492.529000	-4148.265000	14754.167000
1808.476000	-4476.134000	14754.167000
1232.891000	-4944.854000	14754.167000
997.298000	-5130.652000	14754.167000
745.953000	-5307.728000	14754.167000
657.077000	-5351.459000	14754.167000
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377.528000	-5398.897000	14754.167000
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-831.860000	-5252.158000	14754.167000
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-1530.006000	-3786.899000	14754.167000
-1501.204000	-2946.279000	14754.167000

-1484.157000	-2200.354000	14754.167000
-1456.567000	-1508.320000	14754.167000
-1387.756000	-801.222000	14754.167000
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POINTSET	42	
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-200.264000	1631.019000	15245.833000
339.715000	2144.876000	15245.833000
619.760000	2312.975000	15245.833000
885.383000	2432.569000	15245.833000
993.492000	2458.980000	15245.833000
1722.089000	2459.398000	15245.833000
2409.490000	2169.514000	15245.833000
3084.712000	1927.542000	15245.833000
3906.761000	1821.753000	15245.833000
4732.120000	1722.351000	15245.833000
5452.888000	1667.115000	15245.833000
5873.329000	1573.754000	15245.833000
6250.911000	1443.137000	15245.833000
6555.433000	804.906000	15245.833000
6621.739000	0.000000	15245.833000
6689.098000	-821.318000	15245.833000
6760.087000	-1191.986000	15245.833000
6685.859000	-1543.552000	15245.833000
5956.359000	-1935.339000	15245.833000
5441.185000	-2422.572000	15245.833000
4832.027000	-2789.772000	15245.833000
4232.347000	-3189.302000	15245.833000
3630.602000	-3630.602000	15245.833000
2986.203000	-3962.825000	15245.833000
2320.128000	-4185.622000	15245.833000
1641.404000	-4509.721000	15245.833000
1062.842000	-5000.281000	15245.833000
368.070000	-5263.642000	15245.833000
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-731.304000	-5203.495000	15245.833000
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-1523.328000	-3588.736000	15245.833000
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-1589.509000	-1704.540000	15245.833000
-1591.025000	-994.183000	15245.833000
-1293.952000	0.000000	15245.833000
POINTSET	46	
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223.293000	2124.494000	15738.333000
449.789000	2313.964000	15738.333000
708.065000	2469.315000	15738.333000
817.188000	2515.046000	15738.333000
1141.657000	2564.204000	15738.333000
1473.745000	2552.602000	15738.333000
1530.347000	2546.925000	15738.333000
2198.528000	2276.643000	15738.333000
2925.729000	1973.429000	15738.333000
3747.300000	1909.345000	15738.333000
4464.713000	1895.158000	15738.333000
5182.593000	1886.310000	15738.333000
5652.555000	1836.626000	15738.333000
5916.382000	1808.820000	15738.333000
6233.125000	1787.320000	15738.333000
6455.075000	1490.271000	15738.333000
6542.663000	687.662000	15738.333000
6569.735000	-114.675000	15738.333000
6648.013000	-934.317000	15738.333000
6713.177000	1304.909000	15738.333000
6719.304000	-1675.311000	15738.333000
6173.708000	-2005.959000	15738.333000
5525.489000	-2460.106000	15738.333000
4831.939000	-2789.721000	15738.333000
4197.655000	-3163.160000	15738.333000
3594.345000	-3594.345000	15738.333000
2950.497000	-3915.442000	15738.333000
2211.133000	-4158.536000	15738.333000
1536.506000	-4462.338000	15738.333000
859.499000	-4874.459000	15738.333000
177.494000	-5082.760000	15738.333000
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-530.587000	-5048.197000	15738.333000
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POINTSET	45	
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36.389000	2084.721000	16230.000000
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604.540000	2424.677000	16230.000000
707.110000	2465.986000	16230.000000
1444.082000	2501.224000	16230.000000
2170.647000	2247.771000	16230.000000
2881.878000	2017.913000	16230.000000
3716.347000	2060.005000	16230.000000
4582.127000	2040.094000	16230.000000
5422.104000	2081.351000	16230.000000
5739.338000	2088.948000	16230.000000
6111.404000	2104.325000	16230.000000
6378.380000	2072.461000	16230.000000
6473.726000	1258.365000	16230.000000
6537.970000	457.179000	16230.000000
6537.239000	-342.602000	16230.000000
6612.105000	-1165.892000	16230.000000
6679.441000	-1542.071000	16230.000000
6681.973000	-1916.025000	16230.000000
6122.165000	-2350.079000	16230.000000
5362.810000	-2615.617000	16230.000000
4676.647000	-2922.293000	16230.000000
4005.884000	-3243.901000	16230.000000
3375.610000	-3619.899000	16230.000000
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1945.644000	-4172.446000	16230.000000
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588.466000	-4792.672000	16230.000000
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POINTSET	43	
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-1904.126000	233.797000	16721.667000
-1581.078000	912.836000	16721.667000
-1024.186000	1409.671000	16721.667000
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197.088000	2252.728000	16721.667000
507.223000	2386.297000	16721.667000
800.900000	2464.917000	16721.667000
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2380.557000	2143.463000	16721.667000
3230.037000	2097.611000	16721.667000
3973.932000	2202.786000	16721.667000
4758.937000	2219.129000	16721.667000
5640.276000	2278.820000	16721.667000
5985.385000	2297.574000	16721.667000
6340.552000	2307.772000	16721.667000
6460.828000	2224.641000	16721.667000
6470.268000	1375.298000	16721.667000
6492.549000	568.024000	16721.667000
6493.133000	-226.745000	16721.667000
6557.675000	1038.634000	16721.667000
6606.722000	-1404.302000	16721.667000
6646.500000	-1780.924000	16721.667000
6700.292000	-2177.057000	16721.667000
6274.383000	-2408.510000	16721.667000
5507.975000	-2686.419000	16721.667000
4719.507000	-2949.075000	16721.667000
3966.325000	-3211.867000	16721.667000
3296.327000	-3534.878000	16721.667000
2599.351000	-3853.696000	16721.667000
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1168.395000	-4360.510000	16721.667000
487.365000	-4636.969000	16721.667000
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POINTSET	38	
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-1895.137000	883.717000	17213.333000
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-37.807000	2165.975000	17213.333000
694.204000	2420.976000	17213.333000
1449.102000	2411.710000	17213.333000
2184.962000	2184.962000	17213.333000
2933.338000	2053.945000	17213.333000
3885.894000	2243.522000	17213.333000
5056.710000	2357.983000	17213.333000
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5998.345000	2423.489000	17213.333000
6364.909000	2443.260000	17213.333000
6465.944000	2100.913000	17213.333000
6457.840000	1255.277000	17213.333000
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6557.856000	-1156.327000	17213.333000
6640.813000	-1904.222000	17213.333000
6700.193000	-2307.062000	17213.333000
6597.723000	-2665.653000	17213.333000
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4296.104000	-3121.302000	17213.333000
3565.253000	-3324.653000	17213.333000
2814.578000	-3602.496000	17213.333000
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POINTSET	38	
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3839.338000	2128.180000	17705.000000
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6283.608000	2538.742000	17705.000000
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6675.691000	-2298.625000	17705.000000
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5219.720000	3013.607000	17705.000000
4479.835000	-3136.814000	17705.000000
3655.127000	-3291.091000	17705.000000
2882.510000	3435.242000	17705.000000
2126.335000	-3682.920000	17705.000000
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POINTSET	40	
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4340.672000	2211.683000	18196.667000
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6637.348000	-2156.605000	18196.667000
6694.609000	-2569.820000	18196.667000
6519.849000	-2902.824000	18196.667000
5724.750000	-3173.281000	18196.667000
4922.256000	-3196.550000	18196.667000
4152.553000	-3244.330000	18196.667000
3298.512000	-3298.512000	18196.667000
2514.385000	-3460.755000	18196.667000
1739.865000	-3731.152000	18196.667000
997.840000	-4002.117000	18196.667000
223.792000	-4270.198000	18196.667000
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-534.685000	-4354.662000	18196.667000
-1251.153000	-4092.336000	18196.667000
-1852.079000	-3341.240000	18196.667000
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-2380.835000	-1860.112000	18196.667000
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-2662.037000	0.000000	18196.667000
POINTSET	41	
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-2748.538000	386.282000	18689.167000
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-1877.102000	1575.076000	18689.167000
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-434.223000	2042.857000	18689.167000
313.193000	2228.483000	18689.167000
1085.876000	2226.376000	18689.167000
1874.797000	2082.173000	18689.167000
2715.593000	2046.346000	18689.167000
3645.452000	2104.702000	18689.167000
4531.895000	2210.353000	18689.167000
5551.616000	2471.739000	18689.167000
5921.923000	2513.707000	18689.167000
6268.779000	2532.751000	18689.167000
6416.397000	2463.024000	18689.167000
6413.680000	1599.110000	18689.167000
6428.600000	789.333000	18689.167000
6459.938000	0.000000	18689.167000
6514.113000	-799.833000	18689.167000
6591.440000	-1643.431000	18689.167000
6617.111000	-2023.054000	18689.167000
6651.014000	-2420.771000	18689.167000
6693.706000	-2841.310000	18689.167000
6336.200000	-3090.371000	18689.167000
5617.369000	-3375.256000	18689.167000
4812.691000	-3369.883000	18689.167000
3946.004000	-3311.091000	18689.167000
3173.229000	3285.975000	18689.167000
2408.277000	3439.376000	18689.167000
1607.516000	3610.540000	18689.167000
896.137000	3881.595000	18689.167000
143.487000	-4108.933000	18689.167000
-219.763000	-4193.326000	18689.167000
-1028.163000	-4123.736000	18689.167000
-1824.037000	-3430.515000	18689.167000
2195.909000	-2711.722000	18689.167000
-2453.736000	-1986.996000	18689.167000
-2604.956000	-1214.711000	18689.167000
-2736.788000	433.465000	18689.167000
-2779.302000	0.000000	18689.167000
POINTSET	40	
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-2817.479000	496.798000	19180.833000
-2520.731000	1229.443000	19180.833000
-1908.479000	1659.016000	19180.833000
-1195.791000	1913.666000	19180.833000
-433.036000	2037.274000	19180.833000
343.769000	2170.470000	19180.833000
1108.666000	2085.097000	19180.833000
1873.743000	2009.343000	19180.833000
2681.015000	2020.290000	19180.833000
3532.235000	2039.337000	19180.833000
4425.928000	2158.669000	19180.833000
5507.473000	2337.784000	19180.833000

6050.485000	2444.555000	19180.833000
6367.479000	2444.246000	19180.833000
6417.193000	1599.986000	19180.833000
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6454.488000	0.000000	19180.833000
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6579.803000	-1640.529000	19180.833000
6639.477000	-2416.572000	19180.833000
6690.241000	-2839.839000	19180.833000
6421.352000	-3131.903000	19180.833000
5711.770000	-3431.978000	19180.833000
4901.829000	-3561.387000	19180.833000
4092.710000	-3434.192000	19180.833000
3245.868000	-3245.868000	19180.833000
2427.444000	-3341.091000	19180.833000
1679.572000	-3443.632000	19180.833000
924.938000	-3709.725000	19180.833000
206.839000	-3946.731000	19180.833000
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-501.521000	-4084.559000	19180.833000
-575.127000	-4092.239000	19180.833000
-935.327000	-4051.347000	19180.833000
-1774.297000	-3482.253000	19180.833000
-2211.446000	-2830.521000	19180.833000
-2503.642000	-2100.805000	19180.833000
-2656.391000	-1353.499000	19180.833000
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POINTSET	41	
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-2005.442000	1682.765000	19672.500000
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221.305000	2105.576000	19672.500000
978.819000	2006.876000	19672.500000
1749.112000	2012.124000	19672.500000
2530.043000	1976.686000	19672.500000
3282.862000	1972.543000	19672.500000
4081.793000	2079.777000	19672.500000
4966.797000	2211.360000	19672.500000
5437.922000	2308.261000	19672.500000
6048.043000	2443.568000	19672.500000
6410.061000	2333.071000	19672.500000
6424.081000	1964.039000	19672.500000
6408.994000	1130.079000	19672.500000
6436.546000	337.325000	19672.500000
6472.030000	452.568000	19672.500000
6542.981000	-1271.827000	19672.500000
6594.624000	-2016.179000	19672.500000
6631.465000	-2413.656000	19672.500000
6643.342000	-2819.932000	19672.500000
6013.703000	-3197.543000	19672.500000
5276.560000	-3426.638000	19672.500000
4275.037000	-3340.025000	19672.500000
3581.095000	-3224.432000	19672.500000
2764.277000	-3179.937000	19672.500000
2016.141000	-3226.500000	19672.500000
1250.859000	-3436.706000	19672.500000
522.296000	-3716.332000	19672.500000
-205.643000	-3923.897000	19672.500000
-556.224000	-3957.737000	19672.500000
-912.743000	-3953.524000	19672.500000
-982.205000	-3939.408000	19672.500000
-1911.728000	-3311.210000	19672.500000
-2330.036000	-2680.400000	19672.500000
-2604.610000	-1962.714000	19672.500000
-2752.113000	1225.320000	19672.500000
-2904.332000	0.000000	19672.500000
POINTSET	41	
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392.307000	2018.246000	20164.167000
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1875.687000	1942.331000	20164.167000
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4975.279000	2215.137000	20164.167000
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6482.869000	-2886.359000	20164.167000
5769.419000	-3198.041000	20164.167000
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3475.105000	-3128.999000	20164.167000
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1978.392000	-3046.457000	20164.167000
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562.302000	-3550.234000	20164.167000
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-1900.685000	-3292.082000	20164.167000
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-2790.331000	-1242.336000	20164.167000
-2951.646000	0.000000	20164.167000
POINTSET	45	
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993.843000	1869.147000	20655.833000
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6029.687000	2436.152000	20655.833000
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6534.503000	-2640.111000	20655.833000
5813.042000	-2961.893000	20655.833000
5132.447000	-3083.885000	20655.833000
4823.085000	-3132.148000	20655.833000
4513.779000	3160.582000	20655.833000
4372.804000	-3177.028000	20655.833000
3356.994000	2718.440000	20655.833000
2663.605000	-2663.605000	20655.833000
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1261.875000	-2972.792000	20655.833000
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POINTSET	44	
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-2489.866000	1161.044000	21148.333000
-1946.563000	1520.822000	21148.333000
-1282.557000	1702.010000	21148.333000
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31.956000	1830.747000	21148.333000
696.583000	1814.661000	21148.333000
1388.158000	1776.761000	21148.333000
2079.287000	1744.729000	21148.333000
2853.115000	1782.824000	21148.333000
3566.365000	1817.154000	21148.333000
4424.756000	1970.028000	21148.333000
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6142.102000	2357.732000	21148.333000
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6403.337000	447.765000	21148.333000
6438.792000	-224.848000	21148.333000
6492.843000	912.510000	21148.333000
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5822.101000	-2471.335000	21148.333000
4909.278000	-2394.415000	21148.333000
4013.031000	-2316.925000	21148.333000
3305.226000	-2229.403000	21148.333000
2617.694000	-2275.526000	21148.333000
1950.248000	-2408.355000	21148.333000
1332.586000	-2615.347000	21148.333000
742.584000	-2978.341000	21148.333000
501.014000	-3163.275000	21148.333000
231.466000	-3310.117000	21148.333000
174.884000	-3336.990000	21148.333000
-479.742000	-3413.540000	21148.333000
-800.962000	-3469.349000	21148.333000
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-1936.502000	-2981.952000	21148.333000
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POINTSET	43	
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-1454.104000	1505.769000	21640.000000
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981.850000	1700.615000	21640.000000
1595.546000	1652.236000	21640.000000
2214.780000	1609.132000	21640.000000
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5130.367000	1969.363000	21640.000000
6145.501000	2236.780000	21640.000000
6391.031000	2076.572000	21640.000000
6392.955000	1833.151000	21640.000000
6391.504000	1712.598000	21640.000000
6394.679000	1012.818000	21640.000000
6409.516000	335.908000	21640.000000
6453.144000	338.195000	21640.000000
6528.466000	-1034.007000	21640.000000
6544.306000	-1391.035000	21640.000000
6588.419000	1642.677000	21640.000000
6011.318000	1837.844000	21640.000000
5172.656000	-1882.693000	21640.000000
4404.196000	1869.470000	21640.000000
3767.338000	1837.454000	21640.000000
3156.597000	-1822.462000	21640.000000
2552.096000	-1854.206000	21640.000000
1940.058000	2008.989000	21640.000000
1380.818000	-2209.770000	21640.000000
869.481000	2525.157000	21640.000000
409.376000	2912.861000	21640.000000
-164.879000	3146.086000	21640.000000
-795.967000	3192.449000	21640.000000
-1374.076000	3086.225000	21640.000000
-2090.486000	2581.535000	21640.000000
-2466.080000	-2069.287000	21640.000000
-2643.513000	1465.323000	21640.000000
-2774.296000	848.187000	21640.000000
-2812.432000	0.000000	21640.000000
POINTSET	44	
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-2581.505000	180.516000	22131.667000
-2348.569000	673.441000	22131.667000
-1918.650000	1020.164000	22131.667000
-1417.144000	1276.003000	22131.667000
-869.264000	1391.113000	22131.667000
-348.678000	1510.290000	22131.667000
172.494000	1641.175000	22131.667000
730.420000	1640.549000	22131.667000
1280.237000	1580.960000	22131.667000
1844.596000	1493.725000	22131.667000
2389.644000	1435.843000	22131.667000
3005.815000	1466.034000	22131.667000
3559.143000	1510.767000	22131.667000
4248.990000	1631.034000	22131.667000
5290.857000	1821.788000	22131.667000
6228.348000	2023.713000	22131.667000
6391.274000	1475.542000	22131.667000
6396.613000	898.985000	22131.667000
6415.503000	336.222000	22131.667000
6439.976000	224.889000	22131.667000
6489.735000	-796.839000	22131.667000
6528.104000	-1033.950000	22131.667000
6569.441000	-1276.970000	22131.667000
6594.972000	-1401.805000	22131.667000
5477.615000	-1365.723000	22131.667000
4703.361000	-1437.962000	22131.667000
4010.536000	-1459.716000	22131.667000
3386.543000	-1437.502000	22131.667000
2773.250000	-1474.563000	22131.667000
2242.316000	-1570.086000	22131.667000
1735.669000	-1735.669000	22131.667000
1217.402000	-1948.250000	22131.667000
772.965000	-2244.852000	22131.667000
314.034000	-2557.601000	22131.667000
-192.056000	-2746.529000	22131.667000
-756.083000	-2821.742000	22131.667000
-1020.528000	-2803.878000	22131.667000
-1236.236000	-2776.632000	22131.667000
-1286.166000	-2758.191000	22131.667000
-2163.084000	-2088.865000	22131.667000
-2438.834000	-1583.797000	22131.667000
-2596.641000	-1049.111000	22131.667000
-2609.011000	0.000000	22131.667000
POINTSET	44	
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-2172.273000	190.049000	22623.333000
-1872.381000	572.444000	22623.333000
-1483.514000	856.507000	22623.333000
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-194.961000	1387.217000	22623.333000
259.697000	1472.816000	22623.333000
715.402000	1466.791000	22623.333000
1178.858000	1404.909000	22623.333000
1636.691000	1325.366000	22623.333000
2145.627000	1238.778000	22623.333000
2618.163000	1220.869000	22623.333000
3178.389000	1220.069000	22623.333000
3656.914000	1259.177000	22623.333000
4417.489000	1350.562000	22623.333000
5689.613000	1631.470000	22623.333000
6340.177000	1698.845000	22623.333000
6401.328000	1244.292000	22623.333000
6411.671000	787.254000	22623.333000
6436.975000	224.784000	22623.333000
6487.508000	-339.996000	22623.333000
6509.113000	-569.474000	22623.333000
6537.774000	-802.738000	22623.333000
5649.690000	-894.823000	22623.333000
5169.369000	-1004.823000	22623.333000
4527.545000	-962.359000	22623.333000
3886.136000	-968.923000	22623.333000
3367.255000	-1029.473000	22623.333000
2833.586000	-1087.712000	22623.333000
2357.078000	-1200.991000	22623.333000
1882.400000	-1367.643000	22623.333000
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1005.544000	-1741.652000	22623.333000
599.915000	1962.235000	22623.333000
150.578000	-2153.360000	22623.333000
-321.989000	2291.070000	22623.333000
-796.108000	2312.065000	22623.333000
-1277.400000	-2212.522000	22623.333000
-1685.634000	-1939.100000	22623.333000
-2026.371000	-1583.175000	22623.333000
-2239.867000	-1141.269000	22623.333000
-2349.684000	-673.761000	22623.333000
-2241.430000	0.000000	22623.333000
POINTSET	44	
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655.861000	1135.985000	23115.000000
1027.315000	1101.660000	23115.000000
1403.692000	1019.842000	23115.000000
1794.852000	954.340000	23115.000000
2133.753000	862.092000	23115.000000
2517.017000	817.828000	23115.000000
2911.534000	780.143000	23115.000000
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6440.508000	905.154000	23115.000000
6446.798000	677.586000	23115.000000
6448.958000	450.955000	23115.000000
6302.195000	110.005000	23115.000000
6227.949000	-108.709000	23115.000000

6165.825000	-215.315000	23115.000000
3881.870000	-271.447000	23115.000000
3543.539000	-435.092000	23115.000000
3151.003000	-555.607000	23115.000000
2761.661000	-688.559000	23115.000000
2383.803000	-820.809000	23115.000000
2049.824000	-955.849000	23115.000000
1715.373000	-1113.976000	23115.000000
1391.247000	-1252.684000	23115.000000
1046.104000	-1388.227000	23115.000000
704.075000	-1509.894000	23115.000000
346.540000	-1630.344000	23115.000000
0.000000	-1736.390000	23115.000000
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-732.078000	-1724.667000	23115.000000
-1077.205000	-1597.021000	23115.000000
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-1554.490000	0.000000	23115.000000

POINTSET	51	
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-1110.285000	58.188000	23360.833000
-938.336000	286.878000	23360.833000
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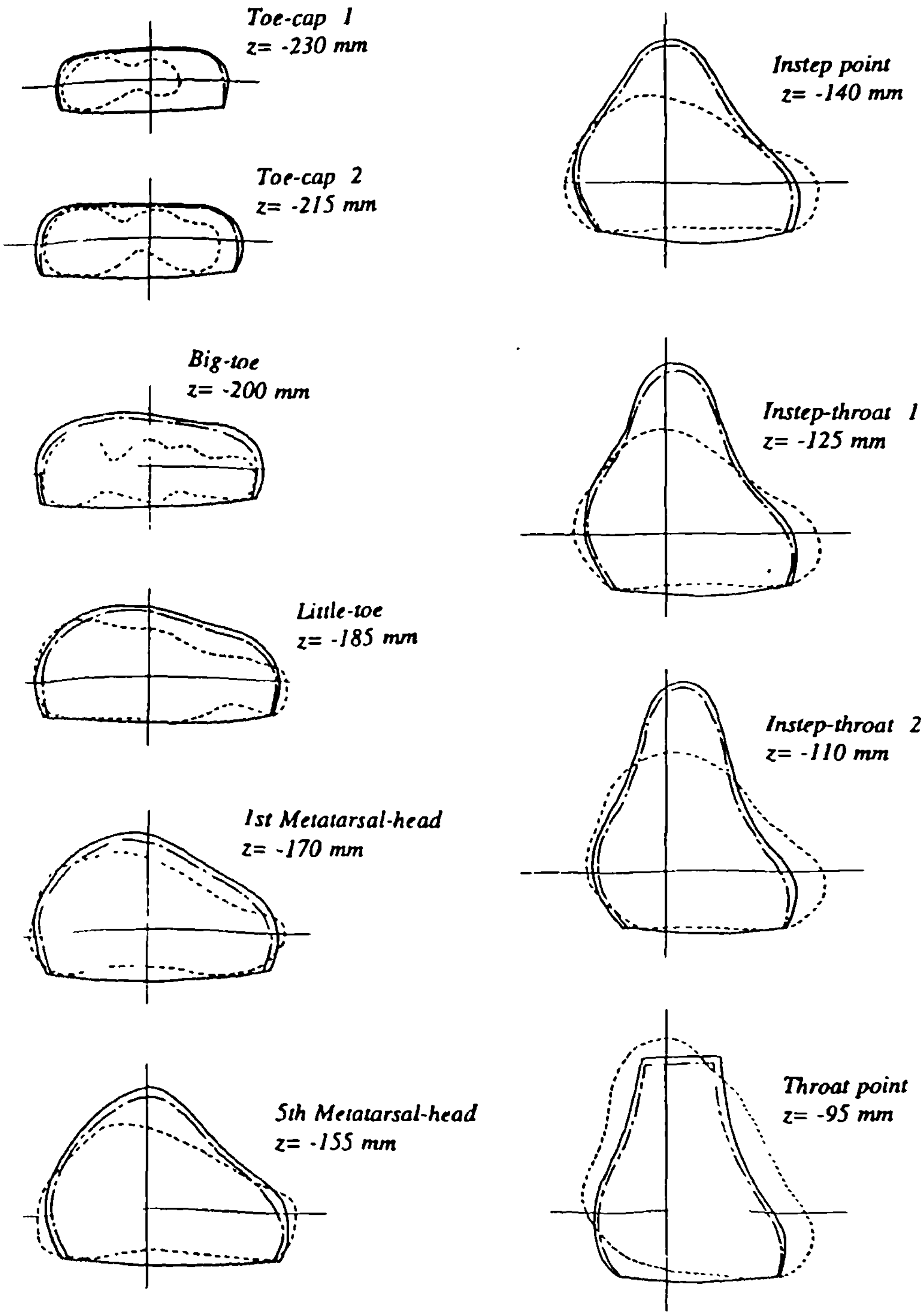
-630.185000	587.657000	23360.833000
-450.113000	720.332000	23360.833000
-251.556000	822.802000	23360.833000
-30.616000	876.733000	23360.833000
189.591000	891.954000	23360.833000
419.225000	899.030000	23360.833000
646.714000	890.125000	23360.833000
877.953000	877.953000	23360.833000
1100.477000	859.787000	23360.833000
1334.141000	770.266000	23360.833000
1545.633000	720.740000	23360.833000
1777.995000	647.137000	23360.833000
1996.853000	535.055000	23360.833000
2228.916000	514.586000	23360.833000
2470.894000	480.293000	23360.833000
2752.280000	435.918000	23360.833000
2876.545000	404.272000	23360.833000
3015.987000	370.317000	23360.833000
3128.553000	273.713000	23360.833000
3173.833000	166.334000	23360.833000
3141.525000	-54.836000	23360.833000
3104.659000	162.708000	23360.833000
3035.689000	-265.588000	23360.833000
2866.623000	351.977000	23360.833000
2556.157000	450.719000	23360.833000
2353.378000	-543.320000	23360.833000
2141.911000	654.848000	23360.833000
1920.122000	737.066000	23360.833000
1724.724000	-841.204000	23360.833000
1514.768000	946.532000	23360.833000
1304.013000	1055.969000	23360.833000
1079.097000	1157.190000	23360.833000
860.114000	1228.370000	23360.833000
633.447000	-1298.759000	23360.833000
418.806000	-1369.854000	23360.833000
198.199000	1410.258000	23360.833000
-25.435000	1457.160000	23360.833000
-258.070000	-1413.587000	23360.833000
-486.401000	-1412.610000	23360.833000
-723.766000	1361.207000	23360.833000
-914.807000	-1259.124000	23360.833000
-1083.551000	-1122.050000	23360.833000
-1199.593000	-937.225000	23360.833000
-1282.695000	-625.612000	23360.833000
-1290.754000	394.623000	23360.833000
-1215.997000	170.897000	23360.833000
-1140.874000	0.000000	23360.833000

POINTSET	49	
-903.331000	0.000000	23484.167000
-854.502000	120.092000	23484.167000
-703.026000	284.041000	23484.167000
-565.471000	457.909000	23484.167000
-508.848000	526.928000	23484.167000
-444.839000	590.321000	23484.167000
-413.158000	612.532000	23484.167000
-210.773000	689.407000	23484.167000
0.000000	730.380000	23484.167000
212.643000	741.573000	23484.167000
440.324000	732.821000	23484.167000
658.083000	705.708000	23484.167000
893.794000	698.308000	23484.167000
1122.790000	648.243000	23484.167000
1339.763000	541.299000	23484.167000
1560.139000	476.983000	23484.167000
1691.178000	421.658000	23484.167000
1774.825000	377.251000	23484.167000
1846.972000	325.671000	23484.167000
1911.035000	234.646000	23484.167000
1913.572000	201.124000	23484.167000
2418.509000	-211.592000	23484.167000
2438.439000	85.152000	23484.167000
2623.692000	45.797000	23484.167000
2543.283000	-44.393000	23484.167000
2397.914000	-125.669000	23484.167000
2368.331000	-248.922000	23484.167000
2305.219000	-323.977000	23484.167000
1900.542000	-301.016000	23484.167000
1789.563000	-479.512000	23484.167000
1604.885000	-648.416000	23484.167000
1415.338000	-784.534000	23484.167000
1215.764000	-916.144000	23484.167000
1007.127000	-1007.127000	23484.167000
795.021000	-1094.253000	23484.167000
574.146000	-1177.174000	23484.167000
357.082000	-1245.294000	23484.167000
133.568000	-1270.811000	23484.167000
-89.858000	-1285.024000	23484.167000
-313.962000	-1259.234000	23484.167000
-522.164000	-1172.801000	23484.167000
-612.251000	-1151.476000	23484.167000
-696.694000	-1114.944000	23484.167000
-737.662000	1093.628000	23484.167000
-918.355000	-770.591000	23484.167000
-1012.552000	-561.267000	23484.167000
-1000.787000	-344.599000	23484.167000
-938.363000	-98.626000	23484.167000
-903.331000	0.000000	23484.167000

POINTSET	33	
-623.621000	0.000000	23607.500000
-587.712000	124.922000	23607.500000
480.661000	312.145000	23607.500000
-306.068000	437.110000	23607.500000
-94.565000	486.495000	23607.500000
118.255000	512.220000	23607.500000
331.893000	511.071000	23607.500000
548.913000	494.243000	23607.500000
769.813000	481.033000	23607.500000
879.042000	467.395000	23607.500000
996.893000	443.845000	23607.500000
1172.539000	292.3470 0	23607.500000
1287.082000	250.183000	23607.500000
1351.521000	165.946000	23607.500000
1420.996000	74.471000	23607.500000
1460.492000	-25.493000	23607.500000
1452.599000	-256.132000	23607.500000
1426.752000	-355.729000	23607.500000
1381.633000	448.920000	23607.500000
1364.892000	-469.970000	23607.500000
1178.623000	626.695000	23607.500000
1000.479000	753.915000	23607.500000
797.076000	854.759000	23607.500000
594.578000	951.5[illegible]400	23607.500000
376.306000	1033.892000	23607.500000
151.016000	1074.535000	23607.500000
-75.144000	1074.607000	23607.500000
302.901000	1056.340000	23607.500000
-537.197000	-930.453000	23607.500000
-680.612000	755.896000	23607.500000
-708.878000	574.179000	23607.500000
-702.278000	312.674000	23607.500000
-623.621000	0.000000	23607.500000

APPENDIX III-III
FOOT AND LAST CROSS-SECTIONS



APPENDIX IV-I

TEST RESULTS OF INTRA-OBSERVER REPEATABILITY IN MEASURES

(unit: mm)

SUBJECTS NUMBER	5D08(11:00)	5D08(12:00)	5D08(22:00)
ITEMS / FOOT	Right(Left)	Right(Left)	Right(Left)
Foot (Stick) Length	238 (240)	238 (239)	236 (238)
Medial Heel to Ball	180 (181)	181 (183)	181 (181)
Medial Heel to Ankle	55 (56)	55 (57)	56 (55)
Heel to Smallest toe	198 (199)	198 (198)	200 (202)
Lateral Heel to Ball	159 (159)	158 (157)	158 (159)
Lateral Heel to Ankle	46 (42)	45 (40)	44 (43)
Joint Girth	221 (223)	224 (223)	221 (222)
Waist Girth	210 (210)	213 (210)	212 (213)
Instep Girth	228 (226)	234 (232)	228 (231)
Long Heel Girth	350 (352)	350 (352)	350 (352)
Short Heel Girth	302 (301)	302 (301)	300 (298)
Medial Malleoli Girth	212 (215)	216 (214)	214 (213)
Big Toe Height	18 (16)	19 (17)	17 (17)
1 Metatarsal-head Height	31 (31)	32 (31)	30 (32)
5 Metatarsal-head Height	21 (21)	21 (21)	21 (21)
Instep Height	47 (49)	49 (49)	49 (51)
Short Heel Height	66 (68)	66 (67)	66 (68)
Medial Malleoli Height	72 (72)	74 (73)	74 (75)
Lateral Malleoli Height	65 (62)	66 (62)	65 (64)

ONE OBSERVER DIFFERENT TIMES OF DAY ON SAME SUBJECT

TEST RESULTS OF INTER-OBSERVER IN MEASURES

(unit: mm)

SUBJECTS NUMBER	5D07(RC)	5D07(JT)	d(RC-JT)
ITEMS / FOOT	Right(Left)	Right(Left)	Right(Left)
Foot (Stick) Length	235 (233)	234 (232)	1 (1)
Medial Heel to Ball	174 (174)	173 (175)	1 (-1)
Medial Heel to Ankle	50 (52)	53 (53)	-3 (-1)
Heel to Smallest toe	195 (197)	193 (193)	2 (4)
Lateral Heel to Ball	158 (158)	159 (160)	-1 (-2)
Lateral Heel to Ankle	47 (49)	50 (51)	-3 (-2)
Joint Girth	227 (228)	227 (227)	0 (1)
Waist Girth	224 (224)	220 (220)	4 (4)
Instep Girth	232 (234)	228 (230)	4 (4)
Long Heel Girth	353 (352)	345 (342)	8 (10)
Short Heel Girth	309 (308)	310 (307)	-1 (1)
Medial Malleoli Girth	230 (237)	232 (234)	-2 (3)
Big Toe Height	21 (23)	20 (20)	1 (3)
1 Metatarsal-head Height	35 (34)	33 (34)	2 (0)
5 Metatarsal-head Height	22 (23)	21 (21)	1 (2)
Instep Height	60 (58)	57 (55)	3 (3)
Short Heel Height	75 (75)	72 (72)	3 (3)
Medial Malleoli Height	80 (83)	82 (84)	-2 (-1)
Lateral Malleoli Height	66 (64)	60 (62)	6 (2)

TWO OBSERVERS, RC & JT, ON SAME SUBJECT

APPENDIX IV-II

FOOT MEASUREMENT CHART (KING'S COLLEGE)

(unit: mm) DATE: / /

SUBJECT NAME			
SUBJECT		RIGHT	LEFT
LENGTH	FOOT (STICK) LENGTH		
	MEDIAL HEEL TO BALL		
	MEDIAL HEEL TO ANKLE		
	HEEL TO SMALLEST TOE		
	LATERAL HEEL TO BALL		
	LATERAL HEEL TO ANKLE		
GIRTH	JOINT GIRTH		
	WAIST GIRTH		
	INSTEP GIRTH		
	LONG HEEL GIRTH		
	SHORT HEEL GIRTH		
	MEDIAL MALLEOLI GIRTH		
HEIGHT	BIG TOE HEIGHT		
	1st METATARSAL-HEAD HEIGHT		
	5th METATARSAL-HEAD HEIGHT		
	INSTEP HEIGHT		
	SHORT HEEL HEIGHT		
	MEDIAL MALLEOLI HEIGHT		
	LATERAL MALLEOLI HEIGHT		
WIDTH	JOINT WIDTH		
	SEAT WIDTH		
DRAFT	OUTLINE DIAGRAM: 1. NORMAL METHOD 2. ORTHOPAEDIC METHOD		

APPENDIX IV-III

LAST MEASUREMENT CHART (KING'S COLLEGE)

(unit: mm) DATE: / /

LAST (size/fit)		
LENGTH	STICK LENGTH	
	TOTAL LENGTH	
	BOTTOM LENGTH	
	MEDIAL HELL TO BALL	
	LATERAL HEEL TO BALL	
	VAMP LENGTH	
GIRTH	JOINT GIRTH	
	WAIST GIRTH	
	INSTEP GIRTH	
	LONG HEEL GIRTH	
	SHORT HEEL GIRTH	
WIDTH	TREAD WIDTH	
	BACKPART WIDTH	
	HEEL SEAT WIDTH	
	BACK CONE TOP WIDTH	
HEIGHT	TOE SPRING	
	TOE DEPTH	
	HEEL PITCH	
	BACK CONE HEIGHT	
	BACKSEAM-TACK HEIGHT	
FEATHERLINE	1. FEATHERLINE 2. FOREPART CENTRE-LINE 3. HEEL SEAT CENTRE-LINE 4. BOTTOM CENTRE-LINE 5. TREAD LINE	

APPENDIX IV-IV

FITTING ASSESSMENT CHART (1/2)
(KING'S COLLEGE)

Shoe Type		Shoes	½ S/D	S/S	½ S/U	Shell	½ S/D	S/S	½ S/U
Last		F/U				F/U			
Subject Name		F/F				F/F			
Subject No.		F/D				F/D			

FOREPART + WAIST

ITEMS	Style	UA	AO	OK	AO	UA	REMARKS
Toe Spring (low/high)	Shoe						
	Shell						
Effective Length (short/long)	Shoe						
	Shell						
Forepart Fit (close/full)	Shoe						
	Shell						
Alignment (inside/outside)	Shoe						
	Shell						
Forepart Depth (close/full)	Shoe						
	Shell						
General Forepart Fit (UA/AO/OK)	Shoe						
	Shell						
Waist Fit (close/full)	Shoe						
	Shell						
Heel to Ball (back/forward)	Shoe						
	Shell						
General Waist Fit (UA/AO/OK)	Shoe						
	Shell						

UA: UnAcceptable.
AO: Acceptable but Obvious.
OK:Fitting well.

FITTING ASSESSMENT CHART (2/2)

INSTEP + QUARTERS + BACKPART							
ITEMS	Style	UA	AO	OK	AO	UA	REMARKS
Balance of Throat Quarters	Shoe	Wrong			Wrong		
	Shell	Wrong			Wrong		
Instep Fit (close/full)	Shoe						
	Shell						
Fastening (right/left)	Shoe	R=			L=		
	Shell	R=			L=		
General Instep Fit (UA/AO/OK)	Shoe						
	Shell						
Toplint Gap/Appearance (close/full)	Shoe						
	Shell						
Under Ankle Height (low/high)	Shoe						
	Shell						
General Quarters Fit (UA/AO/OK)	Shoe						
	Shell						
Seat Width (close/full)	Shoe						
	Shell						
Heel Pitch (back/front)	Shoe						
	Shell						
Heel Curve (pinch/gap)	Shoe						
	Shell						
Heel Grip (tight/loose)	Shoe						
	Shell						
General Backpart Fit (UA/AO/OK)	Shoe						
	Shell						

UA: UnAcceptable.
AO: Acceptable but Obvious.
OK:Fitting well.

APPENDIX IV-V

FOOT MEASUREMENT RECORDS

(1/8)

(unit: mm)

SUBJECTS NUMBER	5D01	5D02	5D03
ITEMS / FOOT	RIGHT (LEFT)	RIGHT (LEFT)	RIGHT (LEFT)
Foot (Stick) Length	239 (236)	239 (237)	235 (239)
Medial Heel to Ball	177 (178)	176 (177)	171 (178)
Medial Heel to Ankle	56 (53)	54 (48)	47 (50)
Heel to Smallest toe	192 (193)	200 (204)	195 (196)
Lateral Heel to Ball	155 (156)	167 (161)	149 (150)
Lateral Heel to Ankle	50 (47)	46 (47)	40 (41)
Joint Girth	229 (232)	225 (228)	230 (235)
Waist Girth	224 (227)	217 (222)	221 (227)
Instep Girth	232 (233)	229 (232)	234 (235)
Long Heel Girth	352 (355)	354 (349)	345 (343)
Short Heel Girth	307 (305)	315 (312)	302 (305)
Medial Malleoli Girth	234 (237)	237 (235)	229 (230)
Big Toe Height	17 (17)	19 (19)	20 (19)
1st Metatarsal-head Height	32 (33)	37 (37)	38 (36)
5th Metatarsal-head Height	23 (21)	25 (23)	21 (22)
Instep Height	57 (57)	56 (56)	61 (59)
Short Heel Height	79 (77)	78 (77)	80 (74)
Medial Malleoli Height	85 (83)	83 (84)	91 (83)
Lateral Malleoli Height	79 (76)	73 (72)	73 (72)
Joint Width*	93 (96)	88 (88)	94 (94)
Seat Width	58 (57)	58 (57)	54 (54)
*Difference (weight-on/off)	10 (11)	11 (11)	12 (11)

DATE: 12 / FEB./ 1992

5D01: V. DYKES
5D02: E. GEAVES
5D03: T. PALLISTER

FOOT MEASUREMENT RECORDS

(2/8)

(unit: mm)

SUBJECTS NUMBER	5D04	5D05	5D06
ITEMS / FOOT	RIGHT (LEFT)	RIGHT (LEFT)	RIGHT (LEFT)
Foot (Stick) Length	239 (237)	238 (240)	241 (242)
Medial Heel to Ball	172 (178)	176 (181)	180 (189)
Medial Heel to Ankle	48 (47)	54 (50)	47 (51)
Heel to Smallest toe	196 (197)	201 (202)	204 (204)
Lateral Heel to Ball	147 (148)	160 (156)	162 (162)
Lateral Heel to Ankle	35 (35)	40 (41)	41 (42)
Joint Girth	238 (236)	233 (232)	233 (232)
Waist Girth	227 (226)	215 (221)	228 (227)
Instep Girth	238 (239)	233 (233)	240 (235)
Long Heel Girth	339 (344)	350 (345)	358 (357)
Short Heel Girth	305 (307)	305 (306)	315 (320)
Medial Malleoli Girth	234 (235)	225 (225)	233 (235)
Big Toe Height	22 (21)	15 (16)	22 (23)
1st Metatarsal-head Height	37 (34)	35 (37)	38 (38)
5th Metatarsal-head Height	23 (24)	24 (27)	26 (27)
Instep Height	58 (59)	61 (57)	56 (57)
Short Heel Height	82 (80)	77 (80)	78 (78)
Medial Malleoli Height	81 (84)	81 (82)	83 (84)
Lateral Malleoli Height	76 (74)	70 (74)	74 (72)
Joint Width*	94 (93)	94 (93)	90 (90)
Seat Width	57 (56)	61 (61)	63 (61)
*Difference (weight-on/off)	7 (9)	9 (12)	13 (13)

DATE: 12 / FEB./ 1992

5D04: C. MASHALL
5D05: J. BARTLETT
5D06: S. DAVIES

FOOT MEASUREMENT RECORDS

(3/8)

(unit: mm)

SUBJECTS NUMBER	5D07	5D08	5D09
ITEMS / FOOT	RIGHT (LEFT)	RIGHT (LEFT)	RIGHT (LEFT)
Foot (Stick) Length	235 (233)	236 (238)	236 (239)
Medial Heel to Ball	174 (174)	181 (181)	175 (181)
Medial Heel to Ankle	50 (52)	56 (55)	56 (53)
Heel to Smallest toe	195 (197)	200 (202)	199 (200)
Lateral Heel to Ball	158 (158)	158 (159)	159 (159)
Lateral Heel to Ankle	47 (49)	44 (43)	43 (47)
Joint Girth	227 (228)	221 (222)	233 (233)
Waist Girth	224 (224)	212 (213)	227 (228)
Instep Girth	232 (234)	228 (231)	237 (236)
Long Heel Girth	353 (352)	350 (352)	359 (357)
Short Heel Girth	309 (308)	300 (298)	310 (316)
Medial Malleoli Girth	230 (237)	214 (213)	230 (234)
Big Toe Height	21 (23)	17 (17)	23 (23)
1st Metatarsal-head Height	35 (34)	30 (32)	36 (35)
5th Metatarsal-head Height	22 (23)	21 (21)	25 (27)
Instep Height	60 (58)	49 (51)	55 (58)
Short Heel Height	75 (75)	66 (68)	81 (77)
Medial Malleoli Height	80 (83)	74 (75)	84 (84)
Lateral Malleoli Height	66 (64)	65 (64)	73 (69)
Joint Width*	92 (91)	90 (88)	91 (91)
Seat Width	60 (60)	55 (57)	63 (62)
*Difference (weight-on/off)	10 (8)	12 (11)	7 (7)

DATE: 25 / FEB./ 1992

5D07: J. PERRY
5D08: L.C. CHANG
5D09: E. HUMPHRIES

FOOT MEASUREMENT RECORDS

(4/8)

(unit: mm)

SUBJECTS NUMBER	5D10		
ITEMS / FOOT	RIGHT(LEFT)	RIGHT(LEFT)	RIGHT(LEFT)
Foot (Stick) Length	235 (237)		
Medial Heel to Ball	177 (179)		
Medial Heel to Ankle	53 (49)		
Heel to Smallest toe	196 (199)		
Lateral Heel to Ball	158 (158)		
Lateral Heel to Ankle	40 (42)		
Joint Girth	226 (224)		
Waist Girth	217 (214)		
Instep Girth	232 (231)		
Long Heel Girth	351 (349)		
Short Heel Girth	320 (321)		
Medial Malleoli Girth	239 (236)		
Big Toe Height	19 (23)		
1st Metatarsal-head Height	37 (37)		
5th Metatarsal-head Height	24 (25)		
Instep Height	64 (62)		
Short Heel Height	88 (85)		
Medial Malleoli Height	86 (88)		
Lateral Malleoli Height	74 (76)		
Joint Width*	89 (86)		
Seat Width	58 (58)		
*Difference (weight-on/off)	7 (6)		

DATE: 25 / FEB./ 1992

5D10: A. NEVILLE

FOOT MEASUREMENT RECORDS

(5/8)

(unit: mm)

SUBJECTS NUMBER	4E01	4E02	4E03
ITEMS / FOOT	RIGHT (LEFT)	RIGHT (LEFT)	RIGHT (LEFT)
Foot (Stick) Length	227 (227)	233 (231)	226 (223)
Medial Heel to Ball	166 (170)	171 (170)	173 (170)
Medial Heel to Ankle	50 (49)	42 (44)	51 (44)
Heel to Smallest toe	191 (192)	194 (189)	193 (194)
Lateral Heel to Ball	146 (147)	157 (153)	158 (155)
Lateral Heel to Ankle	37 (37)	37 (40)	44 (37)
Joint Girth	227 (226)	222 (221)	233 (235)
Waist Girth	224 (223)	218 (218)	221 (224)
Instep Girth	229 (226)	221 (224)	239 (235)
Long Heel Girth	339 (337)	329 (334)	340 (339)
Short Heel Girth	306 (305)	285 (285)	309 (305)
Medial Malleoli Girth	227 (230)	215 (220)	230 (225)
Big Toe Height	23 (21)	18 (19)	20 (24)
1st Metatarsal-head Height	37 (35)	34 (37)	32 (34)
5th Metatarsal-head Height	24 (24)	24 (23)	23 (24)
Instep Height	62 (59)	50 (55)	58 (61)
Short Heel Height	79 (76)	76 (73)	80 (84)
Medial Malleoli Height	83 (79)	79 (79)	77 (83)
Lateral Malleoli Height	74 (76)	72 (69)	73 (70)
Joint Width*	89 (90)	87 (86)	94 (93)
Seat Width	57 (56)	55 (54)	58 (59)
*Difference (weight-on/off)	7 (8)	7 (8)	13 (11)

DATE: 12 / FEB./ 1992

4E01: A. HARRISON
4E02: R. MAPSTONE
4E03: K. CLIFF-JONES

FOOT MEASUREMENT RECORDS

(6/8)

(unit: mm)

SUBJECTS NUMBER	4E04	4E05	4E06
ITEMS / FOOT	RIGHT(LEFT)	RIGHT(LEFT)	RIGHT(LEFT)
Foot (Stick) Length	221 (220)	227 (230)	227 (224)
Medial Heel to Ball	165 (165)	165 (170)	169 (164)
Medial Heel to Ankle	50 (49)	51 (49)	44 (47)
Heel to Smallest toe	180 (180)	180 (181)	180 (190)
Lateral Heel to Ball	137 (140)	145 (147)	147 (145)
Lateral Heel to Ankle	37 (37)	40 (38)	38 (40)
Joint Girth	220 (223)	219 (219)	227 (222)
Waist Girth	216 (218)	211 (214)	215 (216)
Instep Girth	225 (224)	226 (229)	229 (226)
Long Heel Girth	326 (323)	334 (332)	332 (331)
Short Heel Girth	293 (297)	301 (305)	303 (302)
Medial Malleoli Girth	215 (219)	223 (221)	230 (236)
Big Toe Height	18 (17)	18 (21)	17 (17)
1st Metatarsal-head Height	37 (37)	35 (37)	36 (37)
5th Metatarsal-head Height	25 (24)	24 (23)	24 (24)
Instep Height	56 (58)	54 (53)	61 (60)
Short Heel Height	76 (76)	77 (75)	81 (75)
Medial Malleoli Height	75 (76)	80 (76)	79 (78)
Lateral Malleoli Height	70 (72)	73 (70)	72 (69)
Joint Width*	87 (89)	88 (89)	88 (88)
Seat Width	55 (54)	57 (58)	57 (58)
*Difference (weight-on/off)	8 (9)	10 (12)	8 (7)

DATE: 12 / FEB./ 1992

4E04: S. EDWARDS
4E05: S. BEYNON
4E06: A. TONKINS

FOOT MEASUREMENT RECORDS

(7/8)

(unit: mm)

SUBJECTS NUMBER	4E07	4E08	
ITEMS / FOOT	RIGHT (LEFT)	RIGHT (LEFT)	RIGHT (LEFT)
Foot (Stick) Length	231 (230)	232 (233)	
Medial Heel to Ball	169 (172)	172 (172)	
Medial Heel to Ankle	51 (53)	50 (53)	
Heel to Smallest toe	198 (197)	185 (189)	
Lateral Heel to Ball	155 (150)	145 (145)	
Lateral Heel to Ankle	43 (44)	36 (37)	
Joint Girth	227 (233)	239 (236)	
Waist Girth	223 (225)	227 (226)	
Instep Girth	232 (234)	239 (242)	
Long Heel Girth	340 (341)	351 (352)	
Short Heel Girth	302 (301)	316 (317)	
Medial Malleoli Girth	232 (235)	239 (240)	
Big Toe Height	18 (19)	24 (22)	
1st Metatarsal-head Height	34 (36)	37 (37)	
5th Metatarsal-head Height	21 (23)	28 (25)	
Instep Height	51 (53)	56 (58)	
Short Heel Height	72 (71)	75 (79)	
Medial Malleoli Height	75 (79)	84 (82)	
Lateral Malleoli Height	64 (64)	66 (70)	
Joint Width*	91 (92)	96 (92)	
Seat Width	57 (57)	63 (63)	
*Difference (weight-on/off)	10 (7)	7 (6)	

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4E07: K. COLES
4E08: B. PORTER

FOOT MEASUREMENT RECORDS

(8/8)

(unit: mm)

SUBJECTS NUMBER	3F01		
ITEMS / FOOT	RIGHT(LEFT)	RIGHT(LEFT)	RIGHT(LEFT)
Foot (Stick) Length	223 (226)		
Medial Heel to Ball	162 (167)		
Medial Heel to Ankle	40 (42)		
Heel to Smallest toe	178 (181)		
Lateral Heel to Ball	143 (145)		
Lateral Heel to Ankle	32 (34)		
Joint Girth	209 (210)		
Waist Girth	205 (207)		
Instep Girth	222 (220)		
Long Heel Girth	311 (311)		
Short Heel Girth	273 (275)		
Medial Malleoli Girth	205 (210)		
Big Toe Height	20 (18)		
1st Metatarsal-head Height	34 (35)		
5th Metatarsal-head Height	22 (23)		
Instep Height	50 (51)		
Short Heel Height	69 (65)		
Medial Malleoli Height	73 (74)		
Lateral Malleoli Height	66 (62)		
Joint Width*	82 (81)		
Seat Width	54 (54)		
*Difference (weight-on/off)	11 (8)		

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3F01: G. BROOKS

APPENDIX IV-VI

DIFFERENCES BETWEEN LAST AND FOOT
D(x)=last.x-foot.x

(unit: mm)

d(x)		d(SL)	d(MHB)	d(LHB)	d(JG)	d(WG)	d(IG)	d(LHG)	d(SHG)	d(JW)	d(SW)
8615	3F01	18 (15)	-2 (-7)	0 (-2)	1 (0)	3 (1)	-9 (-7)	17 (17)	16 (14)	-4 (-3)	-1 (-1)
8676D	4E01	20 (20)	-3 (-7)	2 (1)	-16(-15)	-16(-15)	-12(-10)	0 (2)	11 (12)	-11(-12)	-2 (-1)
	4E02	14 (16)	-8 (-7)	-9 (-5)	-11(-10)	-10(-10)	-4 (-7)	10 (5)	32 (32)	-9 (-8)	0 (1)
	4E03	21 (24)	-10 (-7)	-10 (-7)	-22(-24)	-13(-16)	-22(-18)	-1 (0)	8 (12)	-16(-15)	-3 (-4)
	4E04	26 (27)	-2 (-2)	11 (8)	-9(-12)	-8(-10)	-8 (-7)	13 (16)	24 (20)	-9(-11)	0 (1)
	4E05	20 (17)	-2 (-7)	3 (1)	-8 (-8)	-3 (-6)	-9(-12)	5 (7)	16 (12)	-10(-11)	-2 (-3)
	4E06	20 (23)	-6 (-1)	1 (3)	-16(-11)	-7 (-8)	-12 (-9)	7 (8)	14 (15)	-10(-10)	-2 (-3)
	4E07	16 (17)	-6 (-9)	-7 (-2)	-16(-22)	-15(-17)	-15(-17)	-1 (-2)	15 (16)	-13(-14)	-2 (-2)
	4E08	15 (14)	-9 (-9)	3 (3)	-28(-25)	-19(-18)	-22(-25)	-12(-13)	1 (0)	-18(-14)	-5 (-5)
8933	5D01	15 (18)	-12(-13)	-5 (-6)	-2 (-5)	0 (-3)	4 (3)	-2 (-5)	15 (17)	-6 (-9)	6 (7)
	5D02	15 (17)	-11(-12)	-17(-11)	2 (-1)	7 (2)	7 (4)	-4 (1)	7 (10)	-1 (-1)	6 (7)
	5D03	19 (15)	-6(-13)	1 (0)	-3 (-8)	3 (-3)	2 (1)	5 (7)	20 (17)	-7 (-7)	10 (10)
	5D04	15 (17)	-7(-13)	3 (2)	-11 (-9)	-3 (-2)	-2 (-3)	11 (6)	17 (15)	-7 (-6)	7 (8)
	5D05	16 (14)	-11(-16)	-10 (-6)	-6 (-5)	9 (3)	3 (3)	0 (5)	17 (16)	-7 (-6)	3 (3)
	5D06	13 (12)	-15(-24)	-12(-12)	-6 (-5)	-4 (-3)	-4 (1)	-8 (-7)	7 (2)	-3 (-3)	1 (3)
	5D07	19 (21)	-9 (-9)	-8 (-8)	0 (-1)	0 (0)	4 (2)	-3 (-2)	13 (14)	-5 (-4)	4 (4)
	5D08	18 (16)	-16(-16)	-8 (-9)	6 (5)	12 (11)	8 (5)	0 (-2)	22 (24)	-3 (-1)	9 (7)
	5D09	18 (15)	-10(-16)	-9 (-9)	-6 (-6)	-3 (-4)	-1 (0)	-9 (-7)	12 (6)	-4 (-4)	1 (2)
	5D10	19 (17)	-12(-14)	-8 (-8)	1 (3)	7 (10)	4 (5)	-1 (1)	2 (1)	-2 (1)	6 (6)
9036/	5D01	15 (18)	-8 (-9)	-8 (-9)	-3 (-6)	-2 (-5)	-2 (-3)	-7(-10)	10 (12)	-8(-11)	1 (2)
	5D02	15 (17)	-7 (-8)	-20(-14)	1 (-2)	5 (0)	1 (-2)	-9 (-4)	2 (5)	-3 (-3)	1 (2)
	5D03	19 (15)	-2 (-9)	-2 (-3)	-4 (-9)	1 (-5)	-4 (-5)	0 (2)	15 (12)	-9 (-9)	5 (5)
	5D04	15 (17)	-3 (-9)	0 (-1)	-12(-10)	-5 (-4)	-8 (-9)	6 (1)	12 (10)	-9 (-8)	2 (3)
	5D05	16 (14)	-7(-12)	-13 (-9)	-7 (-6)	7 (1)	-3 (-3)	-5 (0)	12 (11)	-9 (-8)	-2 (-2)
	5D06	13 (12)	-11(-20)	-15(-15)	-7 (-6)	-6 (-5)	-10 (-5)	-13(-12)	2 (-3)	-5 (-5)	-4 (-2)
	5D07	19 (21)	-5 (-5)	-11(-11)	-1 (-2)	-2 (-2)	-2 (-4)	-8 (-7)	8 (9)	-7 (-6)	-1 (-1)
	5D08	18 (16)	-12(-12)	-11(-12)	5 (4)	10 (9)	2 (-1)	-5 (-7)	17 (19)	-5 (-3)	4 (2)
	5D09	18 (15)	-6(-12)	-12(-12)	-7 (-7)	-5 (-6)	-7 (-6)	-14(-12)	7 (1)	-6 (-6)	-4 (-3)
	5D10	19 (17)	-8(-10)	-11(-11)	0 (2)	5 (8)	-2 (-1)	-6 (-4)	-3 (-4)	-4 (-1)	1 (1)
8892	5D01	13 (16)	-12(-13)	-9(-10)	1 (-2)	3 (0)	0 (-1)	-9(-12)	17 (19)	-13(-16)	1 (2)
	5D02	13 (15)	-11(-12)	-21(-15)	5 (2)	10 (5)	3 (0)	-11 (-6)	9 (12)	-8 (-8)	1 (2)
	5D03	17 (13)	-6(-13)	-3 (-4)	0 (-5)	6 (0)	-2 (-3)	-2 (0)	22 (19)	-14(-14)	5 (5)
	5D04	13 (15)	-7(-13)	-1 (-2)	-8 (-6)	0 (1)	-6 (-7)	4 (-1)	19 (17)	-14(-13)	2 (3)
	5D05	14 (12)	-11(-16)	-10 (-6)	-3 (-2)	12 (6)	-1 (-1)	-7 (-2)	19 (18)	-14(-13)	-2 (-2)
	5D06	11 (10)	-15(-24)	-16(-16)	-3 (-2)	-1 (0)	-8 (-3)	-15(-14)	9 (4)	-10(-10)	-4 (-2)
	5D07	17 (19)	-9 (-9)	-12(-12)	3 (2)	3 (3)	0 (-2)	-10 (-9)	15 (16)	-12(-11)	-1 (-1)
	5D08	16 (14)	-16(-16)	-12(-13)	9 (8)	15 (14)	4 (1)	-7 (-9)	24 (26)	-10 (-8)	4 (2)
	5D09	16 (13)	-10(-16)	-13(-13)	-3 (-3)	0 (-1)	-5 (-4)	-16(-14)	14 (8)	-11(-11)	-4 (-3)
	5D10	17 (15)	-12(-14)	-12(-12)	4 (6)	10 (13)	0 (1)	-8 (-6)	4 (4)	-9 (-6)	1 (1)

APPENDIX IV-VII

FITTING ASSESSMENT RECORDS

TOE SPRING (1.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES			*		
		SHELLS			*		
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS					
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

TOE SPRING (1.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS					
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

EFFECTIVE LENGTH (2.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES					*
		SHELLS					*
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES			*		
		SHELLS			*		
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES		*			
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	

EFFECTIVE LENGTH (2.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D05	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D06	NOCTURNE	SHOES	*				
		SHELLS	*				
	OHIO (MOC)	SHOES	*				
		SHELLS	*				
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

FOREPART FIT (3.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES		*			
		SHELLS		*			
4E02	POP-LIFE	SHOES		*			
		SHELLS		*			
4E03	POP-LIFE	SHOES	*				
		SHELLS	*				
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES		*			
		SHELLS		*			
4E07	POP-LIFE	SHOES		*			
		SHELLS		*			
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES		*			
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	

FOREPART FIT (3.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D05	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	
3F01		SHOES				*	
		SHELLS				*	

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FITTING ASSESSMENT RECORDS

ALIGNMENT (4.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			?		
		SHELLS			?		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES			?		
		SHELLS			?		
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

ALIGNMENT (4.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES			?		
		SHELLS			?		
	OHIO (MOC)	SHOES			?		
		SHELLS			?		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			?		
		SHELLS			?		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D09	NOCTURNE	SHOES			?		
		SHELLS			?		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

FOREPART DEPTH (5.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES	*				
		SHELLS	*				
4E02	POP-LIFE	SHOES		*			
		SHELLS		*			
4E03	POP-LIFE	SHOES	*				
		SHELLS	*				
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES		*			
		SHELLS		*			
4E06	POP-LIFE	SHOES		*			
		SHELLS		*			
4E07	POP-LIFE	SHOES		*			
		SHELLS		*			
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

FOREPART DEPTH (5.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES				*	
		SHELLS				*	
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	
3F01		SHOES				*	
		SHELLS				*	

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FITTING ASSESSMENT RECORDS

WAIST FIT (6.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES		*			
		SHELLS		*			
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES		*			
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

WAIST FIT (6.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES				*	
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES				*	
		SHELLS				*	

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FITTING ASSESSMENT RECORDS

HEEL TO BALL (7.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES		*			
		SHELLS		*			
4E03	POP-LIFE	SHOES		*			
		SHELLS		*			
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES		*			
		SHELLS		*			

HEEL TO BALL (7.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES		*			
		SHELLS		*			
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

INSTEP FIT (8.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES		*			
		SHELLS		*			
4E02	POP-LIFE	SHOES		*			
		SHELLS		*			
4E03	POP-LIFE	SHOES	*				
		SHELLS	*				
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES		*			
		SHELLS		*			
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	

INSTEP FIT (8.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES		*			
		SHELLS		*			
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES	*				
		SHELLS	*				
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES				*	
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES		*			
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS				*	

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FITTING ASSESSMENT RECORDS

TOPLINE GAP/ APPEARANCE (9.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES		*			
		SHELLS		*			
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES	*				
		SHELLS	*				
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

TOPLINE GAP/ APPEARANCE (9.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES				*	
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS				*	
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES				*	
		SHELLS				*	

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FITTING ASSESSMENT RECORDS

UNDER ANKLE HEIGHT (10.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES			*		
		SHELLS			*		
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

UNDER ANKLE HEIGHT (10.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

SEAT WIDTH (11.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES		*			
		SHELLS		*			
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES		*			
		SHELLS		*			
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

SEAT WIDTH (11.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D09	NOCTURNE	SHOES		*			
		SHELLS		*			
	OHIO (MOC)	SHOES		*			
		SHELLS		*			
	2nd NATURE	SHOES		*			
		SHELLS		*			
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

HEEL PITCH (12.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES			*		
		SHELLS			*		
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

HEEL PITCH (12.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D08	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

HEEL CURVE (13.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS			*		
4E03	POP-LIFE	SHOES			*		
		SHELLS			*		
4E04	POP-LIFE	SHOES			*		
		SHELLS			*		
4E05	POP-LIFE	SHOES			*		
		SHELLS			*		
4E06	POP-LIFE	SHOES			*		
		SHELLS			*		
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES		*			
		SHELLS		*			
5D01	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		

HEEL CURVE (13.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D05	NOCTURNE	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D06	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES				*	
		SHELLS					*
	OHIO (MOC)	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS				*	
5D08	NOCTURNE	SHOES			*		
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS					*.
5D09	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS			*		

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FITTING ASSESSMENT RECORDS

HEEL GRIP (14.1/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
4E01	POP-LIFE	SHOES			*		
		SHELLS			*		
4E02	POP-LIFE	SHOES			*		
		SHELLS				*	
4E03	POP-LIFE	SHOES			*		
		SHELLS				*	
4E04	POP-LIFE	SHOES			*		
		SHELLS				*	
4E05	POP-LIFE	SHOES			*		
		SHELLS				*	
4E06	POP-LIFE	SHOES		*			
		SHELLS				*	
4E07	POP-LIFE	SHOES			*		
		SHELLS			*		
4E08	POP-LIFE	SHOES		*			
		SHELLS		*			
5D01	NOCTURNE	SHOES				*	
		SHELLS					*
	OHIO (MOC)	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS				*	
5D02	NOCTURNE	SHOES			*		
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D03	NOCTURNE	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS				*	

HEEL GRIP (14.2/14)

SUBJECT	SHOE STYLE		UA-	AO-	OK	AO+	UA+
5D04	NOCTURNE	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS				*	
5D05	NOCTURNE	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS				*	
5D06	NOCTURNE	SHOES			*		
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS			*		
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D07	NOCTURNE	SHOES			*		
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS				*	
5D08	NOCTURNE	SHOES			*		
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES				*	
		SHELLS					*
5D09	NOCTURNE	SHOES		*			
		SHELLS			*		
	OHIO (MOC)	SHOES			*		
		SHELLS				*	
	2nd NATURE	SHOES			*		
		SHELLS			*		
5D10	NOCTURNE	SHOES			*		
		SHELLS				*	
	OHIO (MOC)	SHOES			*		
		SHELLS					*
	2nd NATURE	SHOES			*		
		SHELLS			*		
3F01		SHOES			*		
		SHELLS					*

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APPENDIX V-I

SPECIAL MEASUREMENT & FIT ASSESSMENT CHART (KING'S COLLEGE)

Subject			**Last**			
Style			**Size/Fit**			
Age Groups	16-25	26-35	36-45	46-55	56-65	66&over

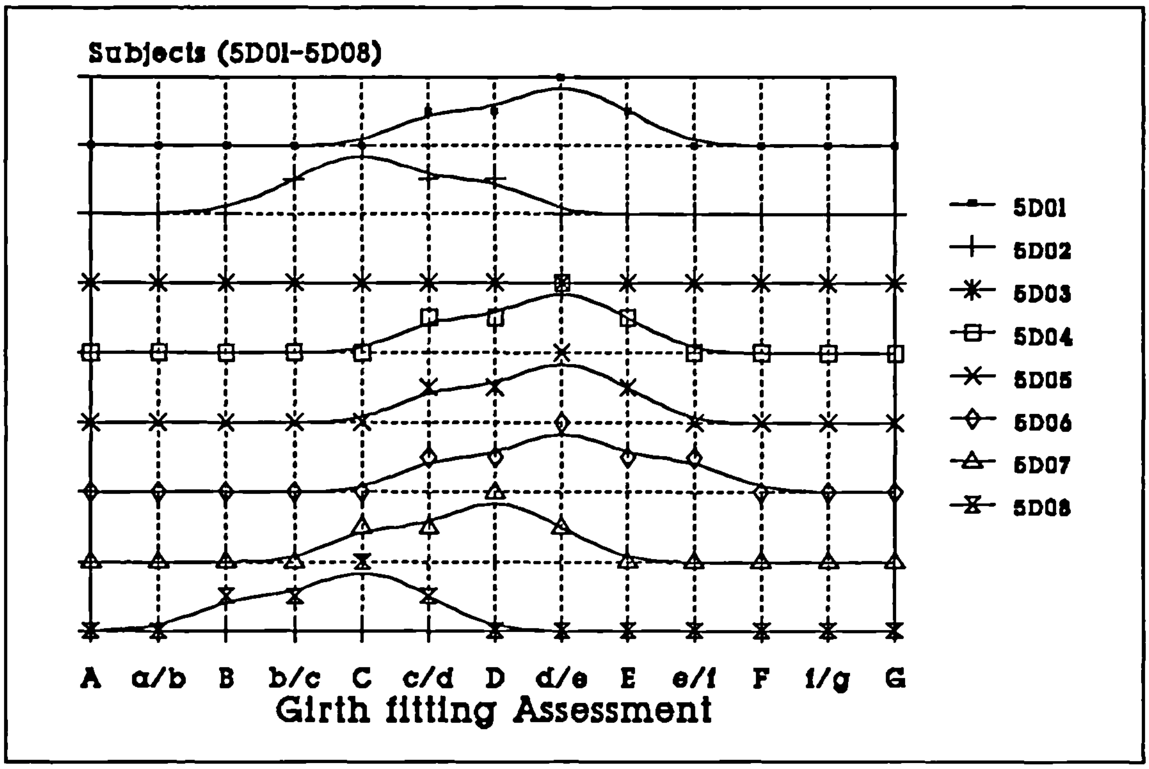
Positions	**Sitting**		**Standing**		**Walking**
	right	left	right	left	right
Stick length					
Heel to ball					
Joint girth					
Waist girth					
Instep girth					
Joint width					
Seat width					
Remarks					

$^1/_2$	B	$^1/_2$	C	$^1/_2$	D	$^1/_2$	E	$^1/_2$	F	$^1/_2$

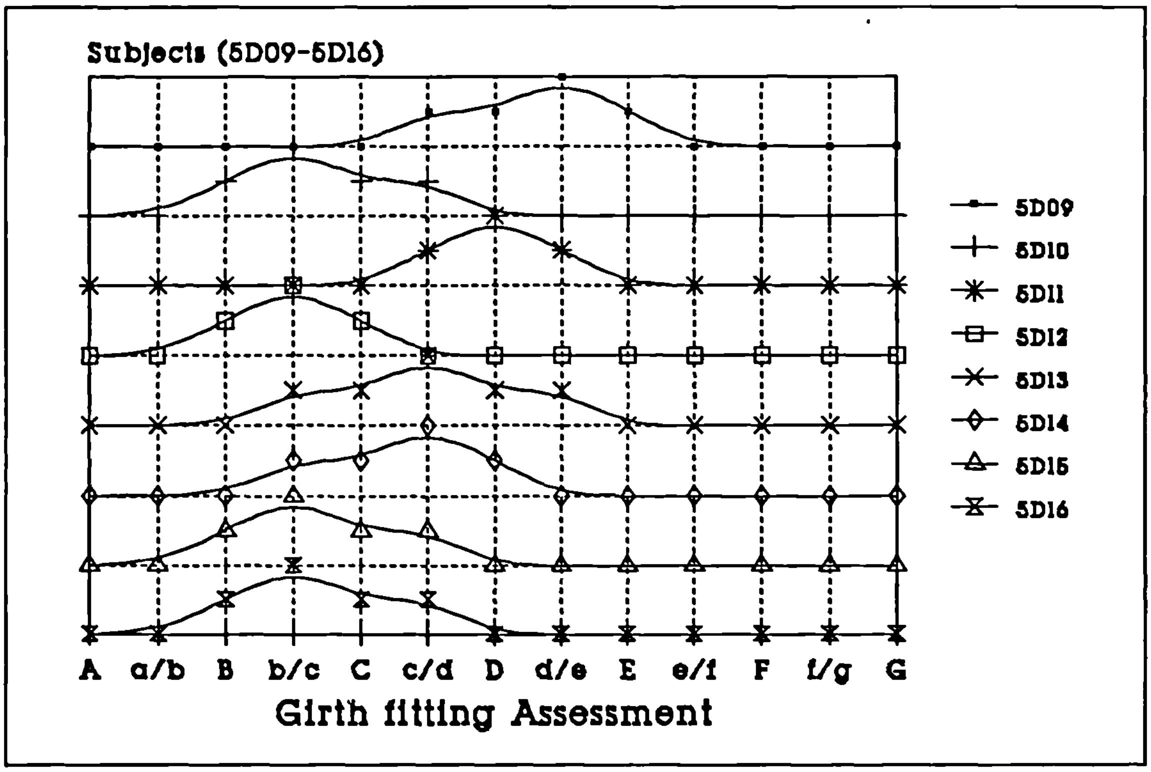
0: UnAcceptable (UA+-).
1: Acceptable but Obvious (AO+-).
2: Fitting well (OK).

APPENDIX V-II

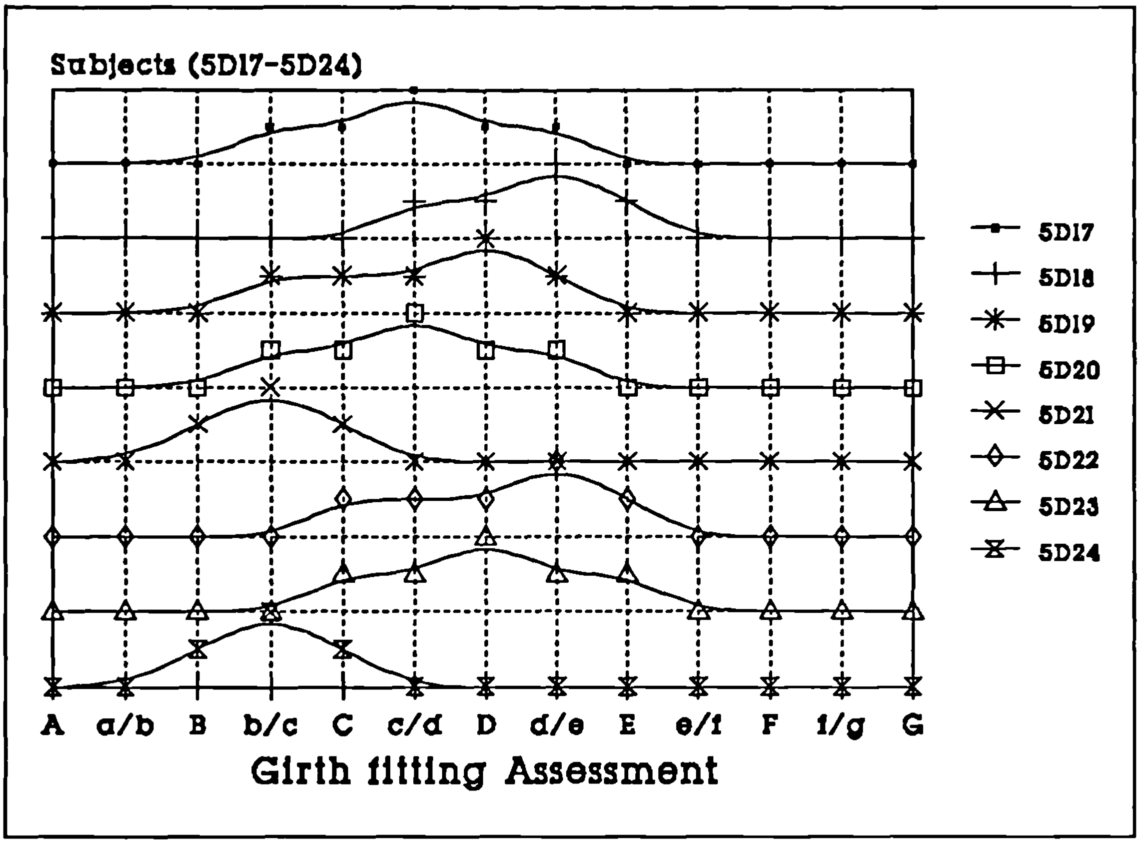
FITTING ASSESSMENT RECORDS (UA-/AO-/OK/AO+/UA+)									
SUBJECT	**B**	**b/c**	**C**	**c/d**	**D**	**d/e**	**E**	**e/f**	**F**
5D01	0	0	0	1	1	2	1	0	0
5D02	0	1	2	1	1	0	0	0	0
5D04	0	0	0	1	1	2	1	0	0
5D05	0	0	0	1	1	2	1	0	0
5D06	0	0	0	1	1	2	1	1	0
5D07	0	0	1	1	2	1	0	0	0
5D08	1	1	2	1	0	0	0	0	0
5D09	0	0	0	1	2	1	1	0	0
5D10	1	2	1	1	0	0	0	0	0
5D11	0	0	0	1	2	1	0	0	0
5D12	1	2	1	0	0	0	0	0	0
5D13	0	1	1	2	1	1	0	0	0
5D14	0	1	1	2	1	0	0	0	0
5D15	1	2	1	1	0	0	0	0	0
5D16	1	2	1	1	0	0	0	0	0
5D17	0	1	1	2	1	1	0	0	0
5D18	0	0	0	1	1	2	1	0	0
5D19	0	1	1	1	2	1	0	0	0
5D20	0	1	1	2	1	1	0	0	0
5D21	1	2	1	0	0	0	0	0	0
5D22	0	0	1	1	1	2	1	0	0
5D23	0	0	1	1	2	1	1	0	0
5D24	1	2	1	0	0	0	0	0	0
TOTAL	7.0	19.0	18.0	24.0	21.0	20.0	8.0	1.0	0.0
No.of OK	0	6	2	4	5	6	0	0	0



RESULTS OF GIRTH FITTING ASSESSMENT (5D01-5D08).



RESULTS OF GIRTH FITTING ASSESSMENT (5D09-5D16).



RESULTS OF GIRTH FITTING ASSESSMENT (5D17-5D24).

APPENDIX V-III

CONFIDENCE INTERVALS FOR THE TRUE CORRELATION COEFFICIENT

SAMPLE SIZE	CRITICAL VALUE (absolute value of *r*)
n= 5	r= 0.88 (r^2= 0.7744)
n= 10	r= 0.63 (r^2= 0.3969)
n= 15	r= 0.51 (r^2= 0.2601)
n= 20	r= 0.44 (r^2= 0.1936)
n= 25	r= 0.39 (r^2= 0.1521)
n= 30	r= 0.36 (r^2= 0.1296)
n= 50	r= 0.28 (r^2= 0.0784)
n= 100	r= 0.20 (r^2= 0.0400)

This table gives the 95% critical points for the absolute value of the correlation coefficient for different sample sizes. When the sample size is small a fairly large absolute value of *r* is required to show significant correlation.

APPENDIX VI-I

INSIDE SHOE EFFECTIVE FOOT LENGTH MEASURING CHART (KING'S COLLEGE)

SUBJECTS	AGE	MEASURING POSITIONS (mm)		
		SITTING	STANDING	WALKING

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